FERTILIZER RESPONSE IN COCONUT:
ANALYSIS INCORPORATING TEMPORAL EFFECTS

by

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D E C L A R A T I O N

Except where otherwise indicated, this dissertation is my own work

August, 1976

N.T.M.H. de Silva

A C K N O W L E D G E M E N T S

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ABSTRACT

The coconut industry occupies a position of great importance in the economy of Sri Lanka. The production of coconut can be increased by both long term and short term methods. These are i) replacement of existing low yielding palms by high yielding varieties and ii) improvement of existing palms by adequate fertilization and better maintenance.

Complex problems arise in proper economic evaluation of the optimal fertilizer policies to be pursued in the industry due to the variety of socio-economic as well as agronomic factors that are encountered. Such policies are however extremely necessary in view of the costs associated with fertilizer usage on one hand and the need to expand coconut production on the other hand in the present economic circumstances of Sri Lanka.

The present study concentrates on the analysis of a set of experimental data on response to fertilizer of coconut obtained from an experiment conducted by the Coconut Research Institute of Sri Lanka, from 1935-1965. Some limitations of earlier analysis of this data by others are discussed, and an attempt is made to incorporate other relevant factors including temporal effects in to the analysis.

The manner in which factors such as response lag, nutrient carry-over in the soil and plant tissues, change in response with ageing etc., that are important in nutrient response of perennial crops should be incorporated into the analysis is discussed. The importance of collection of data on these factors in future experiments is stressed and some possible methods of incorporating these factors in the analysis when only weak data are available is discussed.

Yielding patterns of palms over the period of the experiment under different nutrient combinations are studied. It is observed that under a majority of treatments, the time trend of the yields takes a U-shape.

The reason for such a shape is investigated and it is observed that the change in potassium level in 1950 cannot completely explain this. Possible explanations and their implications for policy are discussed.

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER 1

Introduction

The coconut industry occupies a position of great importance in the economy of Sri Lanka. It contributed 4-6 percent of the Gross Domestic Product and 10 to 18 percent of country's export proceeds during 1970-1975*.

Coconut constitutes an important element in a wide variety of food products, drinks and manufactured goods (see Appendix 'A'). About half of the country's production is consumed domestically and the rest is traded internationally in various processed and semi-processed forms and as fresh nuts. The production consumption and export of coconut for the period 1951 to 1975 are shown in Figure 1.1.

This figure shows, that the consumption has increased steadily over the years. The production of coconuts has fluctuated. These have given rise to a fluctuation and a gradual reduction in the volume of coconut available for export. The decrease and fluctuations of the supply of coconut to the export market may give rise to bad effects on the foreign exchange earnings since the importers of coconut products from Sri Lanka may turn to alternate sources of supply.

The coconut industry provides a means of livelihood to a large sector of people representing not only the primary producers of the crop, but also those who are engaged in industries developed around production, processing and marketing of coconut products. The total work force supported by the coconut industry in Sri Lanka including workers engaged in cottage industries based on coconut fibre would

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* Annual Reports of the Central Bank of Ceylon, 1970-1975.

be over 110,000 (2.48% of the total work force). It is estimated that the total labour force in coconut cultivation alone is about 90,000 which is about 2.04% of the total work force of the country.

1.1 Area Under Cultivation and the Production

The total area under coconut is estimated at about 1.15 million acres**. This is about 7.2 percent of the total land area (excluding the area occupied by the large inland waters), and about 24.7 percent of the agricultural area (Census of Agriculture, 1962).

Most of the acreage under coconut is located in the triangle Colombo-Puttalam-Kurunegala, and in a narrow coastal strip south of Colombo (see Figure 1.2).

The rate of increase in the area under coconut during 1921 to 1962 period was about .98 percent. Though the census data on the area under coconut is not available after 1962, it could be expected that the rate of expansion in the last 14 to 15 years would have been very small or nil due to population expansion and less availability of land suitable for coconut cultivation.

The loss of the area due to population expansion particularly in districts such as Colombo, Kalutara, Kandy, Galle and Matara since the Census of Agriculture 1962 is expected to be around 30,000 acres (see Muthubanda, 1972).

The effect of population pressure has also given rise to fragmentation of holdings which could be expected to combine in the future.

The data presented in Table 1.3 shows that, the holding size appears to have a certain correlation to the per acre yield. Among

** The aerial survey figure of the acreage under coconut is 618,910 (source: A Forest Investory of Ceylon 1966, Hunting Survey Corporation Ltd., Canada-Ceylon Colombo Plan Project). This differs from the 1962 Census and Statistics of Agriculture figure quoted above. The former figure gives the acreage of coconut under pure culture. For most of the planning purposes as well as in expressing and comparing the national average production, the latter figure is used.

TABLE 1.1

DISTRIBUTION OF LAND UNDER AGRICULTURE AND COCONUT IN EACH ADMINISTRATIVE DISTRICT, 1962

District	Distribution of total land area[1]	Agric. area as a % of total land	Area under coconut as a % of agric. area	Distribution of area under coconut
Colombo	3.1	76.4	56.7	19.0
Kalutara	2.4	65.0	14.5	3.2
Kandy	3.6	68.7	5.2	1.8
Matale	3.0	30.8	14.1	1.8
Nuwara Eliya	1.8	57.1	0.8	0.1
Galle	2.5	55.3	16.2	3.2
Matara	1.9	61.9	17.5	3.2
Hambantota	4.0	24.4	32.9	4.4
Jaffna	3.8	27.4	18.0	2.6
Mannar	3.8	6.9	7.8	0.2
Vavuniya	5.7	7.0	5.9	0.3
Batticaloa	3.8	18.0	14.5	1.3
Amparai	4.6	16.3	6.4	0.6
Trincomake	4.0	11.5	5.7	0.3
Kurunegala	7.3	54.7	59.8	33.5
Puttalam	4.6	29.6	66.6	12.6
Anuradhapura	11.1	11.2	6.6	1.1
Polonnaruwa	5.2	11.4	7.1	0.5
Badulla	4.3	31.5	0.5	0.1
Moneragala	11.0	4.7	8.5	0.6
Ratnapura	5.0	41.2	8.5	2.4
Kegalle	2.5	77.4	21.9	6.0
Chilaw[2]				
TOTAL	100.0	29.1	24.7	100.0

Source: Coconut Statistics of Sri Lanka (1945-73).
1. Excludes the area occupied by large inland waters.
2. This district did not exist independently in 1962.

TABLE 1.2

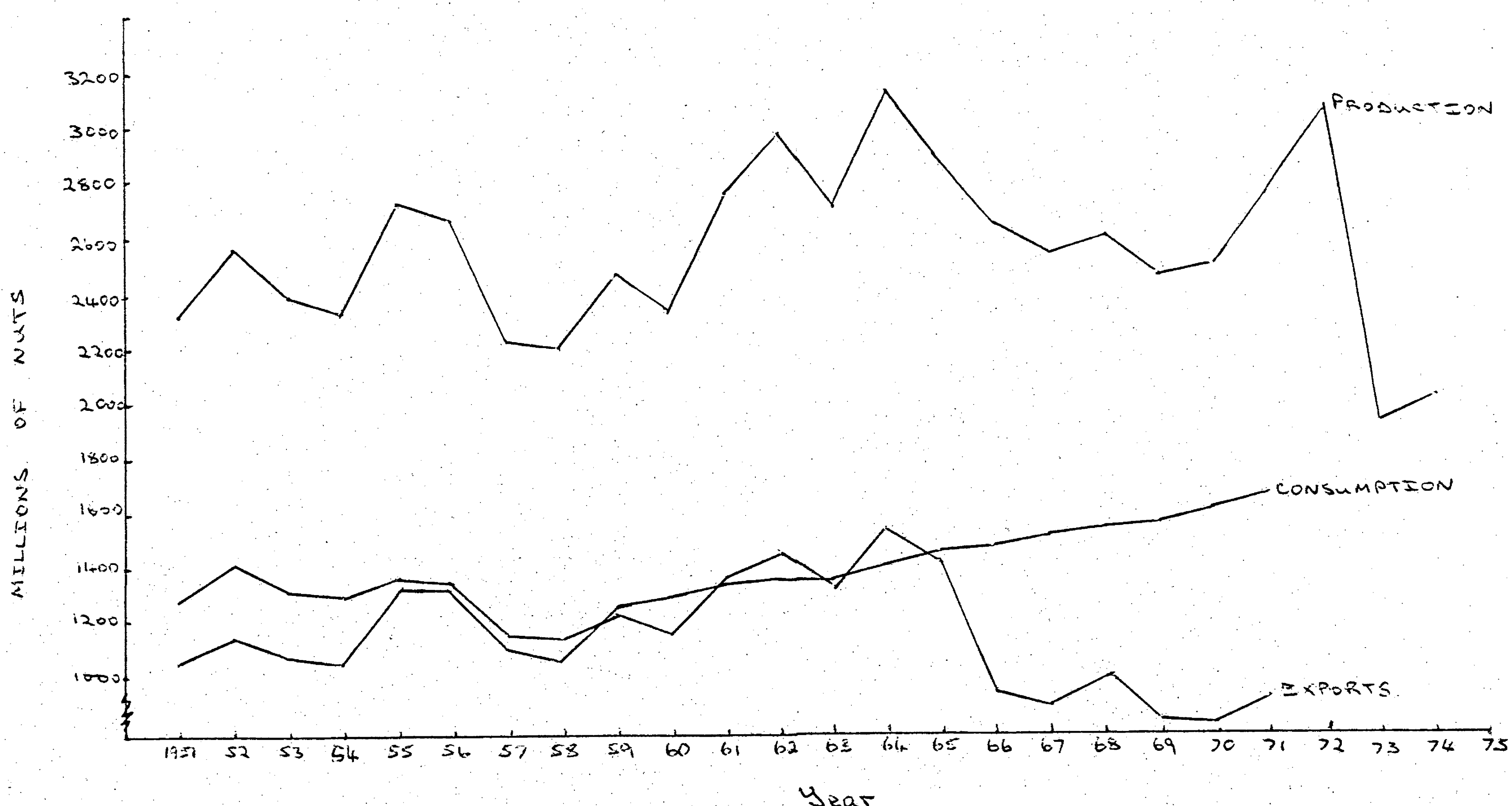
AREA UNDER COCONUT CULTIVATION PER 1000 OF POPULATION

Year	Population[2] (thousands)	Area under cultivation acres
1921	4,522	820,001
1929	5,175	1,076,220
1946	6,854	1,070,942
1962	10,443	1,152,428
1965	11,164[1]	1,152,428
1968	11,992[1]	1,152,428
1971	12,762[1]	1,152,428
1973	13,180[1]	1,152,428

1. 1962 Census figures
2. Mid-year estimate.

Sources: Census of Agriculture 1952; Census of Agriculture 1962; Report of the Registrar General (various years).

FIG.1.1 PRODUCTION, CONSUMPTION AND EXPORT OF COCONUTS, SRI LANKA, 1951-1975



other factors the difference in yield probably reflects the difference in the level of management. It is important to note that about 50 percent of the total production comes from large estates. As compared to country's overall productivity which averages between 2,500 and 3,000 nuts per acre, large estates which are managed efficiently and well maintained, have recorded yields as high as 6,000 nuts per acres. The average yields of small holdings range from 1,000 to 1,500 nuts per acre, or about half the national average.

TABLE 1.3

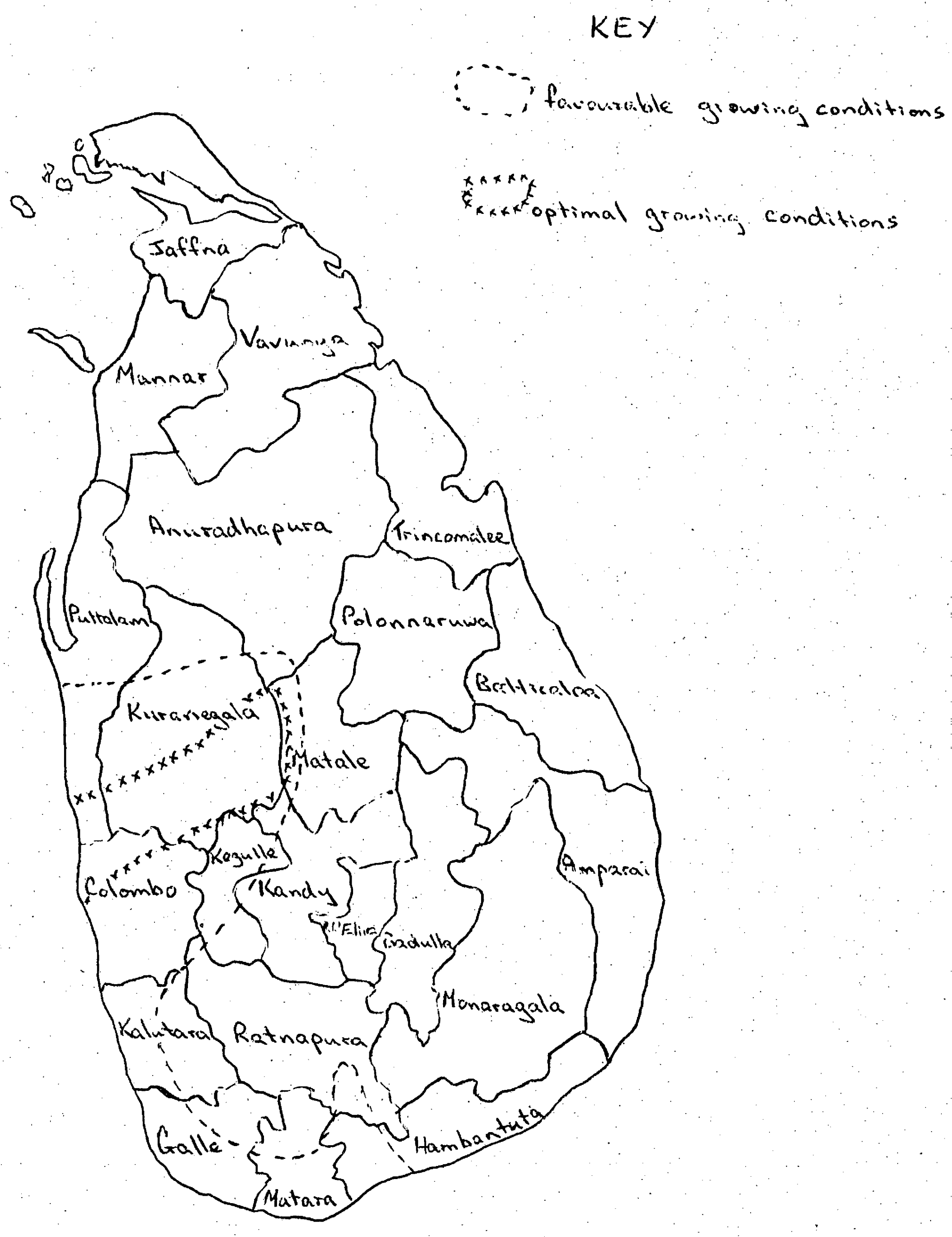
DISTRIBUTION OF SIZE OF COCONUT HOLDINGS AND THE YIELDS

Size of Holding	Extent (%)	Per acre yield
below 1 acre	5.8	
1 acre to 5 acres	29.3	1950
5 acres to 25 acres	29.3	
25 acres to 50 acres	8.9	
50 acres and above	26.8	3150

Sources: Ceylon: Country study on Coconut (1968)
Census of Agriculture, 1962.

The annual production of nuts for the period shown in Figure 1.1 is a fair indication of the long-term and short-term effects on the production of coconut. Due to insufficient data on the acreage of coconut that goes out of production each year, the acreage of coconut that comes in to bearing each year, the quality of fertilizer that is actually applied to the palms, the cultural practices adopted and most importantly the yield records, it is difficult to isolate the long term and short term effects.

Fig.1.2 CLIMATICALLY SUITABLE CULTIVATION AREAS
FOR COCONUTS



Source: Geological Research, Vol.2 (1974)

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* See Appendix 'A'

The production of nuts maintained a fairly steady level up to 1959 (see Figure 1.1) and, thereafter it enjoyed a small rise, and stayed at that level, with minor fluctuations once in three or four years until it reached a peak production of 3,148 million nuts in 1964. The production reached a peak level again in 1972 and started declining with minor fluctuations. The increase in yield during the 1970-72 period appear to be due to the increase in fertilizer dosage during the 1966-71 period.

The decline in yield exhibited after 1972 could be attributed to the effect of drought which prevailed during the course of the year 1972 (which mainly effects 1973 yields) and the gradual decline in the use of fertilizer due to the uncertainty over the ceilling on land.

The annual consumption of fertilizer showed a gradual increase from 1956 onwards and this could clearly be expected due to the Fertilizer Subsidy Scheme which was inaugurated in 1956 (see section 1.3).

Under the replanting scheme which began in 1949, the senile palms were replaced annually using selected planting material. In most years the estimated annual drop in acreage under production due to senility, which is about 7,000 acres (see section 1.2.1) was more than compensated under the above scheme. Allowing a time-lag of 7-10 years as the period between planting and full bearing of a plantation, it could be expected that the replanting scheme also may have contributed towards the change in general level of production from around 1959.

1.2 Increasing Coconut Production in Sri Lanka

The production of coconut in Sri Lanka can be increased by both long-term and short-term agricultural production methods. However for these changes to be adopted coconut cultivation would need to be made more attractive to the farmer than is presently the case. To this end,

TABLE 1.4

INPUT USE AND INDICES FOR EXPORT PRICE AND VOLUME

YEAR	Area (in acres) replanted and newly planted	Total amount of fertilizer used in tons	Fertilizer used per acre in pounds	Estimated production (million nuts)	Export price of the 3 prods.	Export volume of the 3 prods.
1951	6,750	10,250	10	2,345	137	134
1952	6,840	12,030	11	2,574	86	151
1953	6,790	13,200	13	2,403	103	135
1954	6,728	12,500	12	2,349	101	128
1955	9,402	10,500	10	2,746	80	157
1956	10,520	32,000	67	2,661	82	147
1957	13,673	35,000	73	2,229	88	103
1958	14,760	38,430	80	2,201	99	96
1959	17,431	44,000	92	2,491	116	123
1960	23,317	42,176	88	2,362	102	105
1961	27,690	38,800	81	2,796	79	148
1962	20,099	44,983	87	2,993	81	166
1963	23,715	48,687	95	2,704	89	131
1964	17,240	46,408	90	3,148	94	175
1965	16,006	50,102	97	2,853	120	137
1966	18,003	53,952	105	2,621	108	108
1967	18,876	51,193	100	2,577	100	100
1968	21,520	63,209	123	2,601	163	118
1969	19,629	60,901	118	2,440	137	97
1970	20,458	62,358	121	2,510	150	94
1971	19,948	59,148	115	2,799	151	109
1972	15,826	44,836	87	3,073	117	135
1973		49,350	96	1,935	145	45
1974		16,745	33	2,031	435	50

Sources: Census and Statistics Department Reports; Annual Reports of the Central Bank of Ceylon; Ceylon Coconut Quarterly.

the resources devoted to extension, marketing (including freight on fertilizers) and supervised credit for coconut farmers will need to be substantially increased.

1.2.1 Long-term methods

Increasing the land area under coconut and replanting uneconomic senile palms are the two major long-term measures available. In the case of new planting as well as replanting, the per acre yield could be further increased by planting with high yielding planting material suitable for the particular agroclimatic region.

A survey conducted by the Land Utilization Committee in 1968 showed that, the extent of uncultivated land suitable for coconut is about 50,000 acres.

The loss of area under coconut cultivation due to population expansion and urbanization during the period 1946-1962 in the island's best coconut growing districts (see Figure 1.2) such as Colombo, Kalutara, Galle and Matara is estimated at about 50,000 acres or a loss of about 3,125 acres of planted area per annum. Assuming a continuation of this trend the total loss of coconut area in the above districts since the Census of Agriclture in 1962 may well be over 30,000 acres (Muthubanda, 1972). Thus, even if the area under coconut is expanded in the long-run in the uncultivated 50,000 acres of land which is suitable for coconut cultivation, it would appear that, the total land area under coconut would more or less remain the same in the future.

This confirms the opinion that no substantial increase in the island's coconut production could be achieved through the medium of planting new land under coconut. The only other measure open for increasing production under the prevailing technological development therefore, is to follow a <u>systematic replanting procedure</u>.

Though the methodology for estimating the replanting age for perennial crops has been developed (in rubber for instance, see Jayasuriya 1973 and Etherington and Jayasuriya 1976) the optimum economic life cycle however has not been investigated for coconut. But it is generally considered that plantations over 60 years of age which exhibit decreasing yields are due for replanting.

Based on similar criteria as above, it is estimated that 7,000 acres of coconut land need to be replanted each year (Nathanael, 1968) in order to prevent the production decreasing from the present level, (Table 1.4 shows that this level has been exceeded). The Government's

Replanting Programme which is a part of the Rehabilitation Scheme (see section 1.3), has as one of its objectives, the filling of vacancies and replanting of low yielding and/or senile plantations with high yielding planting material. The high-yielding planting material is being supplied to the owners of coconut lands at subsidized prices by the Coconut Research Institute.

The *typica* variety of the coconut palm* which is grown widely in Sri Lanka begins to bear in about 7-10 years and continues to have an 'economic' period of 50-60 years. (See Menon and Pandalia, 1958). This pattern of bearing in coconut palm leads to a much greater degree of inflexibility in the use of resources. In Sri Lanka, a greater portion of the coconut land is in the hands of smallholders. The higher initial capital investment, the inflexibility of the resources and the delayed returns from the initial investment may make many of these farmers to choose investment of their limited capital in short-term cash crops and food crops than replanting their coconut gardens particularly under the present situation where the need for food crops and cash crops are high. These perhaps could be some impediments to the long-term methods of increase in coconut production.

1.2.2 Short-term methods

Improvements in coconut production can be achieved by adopting better management practices such as weed control, soil and moisture conservation, pest and disease control etc, in a fairly short period of time. Most of these practices are more labor intensive and less capital intensive and are therefore advantageous in the case of smallholders.

The increase of coconut production purely by better management practices mentioned above is limited. A number of scientific investigations

*Almost all the 1.15 million acres of coconut land in Sri Lanka is cultivated with *typica* form of the variety *typica*, (Manthriratne, 1971).

have suggested that to obtain a substantial increase in the coconut production, it is important that the palms are adequately and scientifically manured.

For instance according to de Silva (1973) investigation carried out at the Coconut Research Institute of Sri Lanka have shown that yield increases ranging from about 30 percent in richer soils of Chilaw district, to about 200 percent in poor laterite soils of the South-Western Zone, could be obtained for the annual application of 3½ to 5 lb. per palm of fertilizers containing nitrogen, phosphorus and potassium. In general a minimum increase of about 1500 nuts per acre per annum, could be obtained from neglected lands within 3 to 5 years, by the annual application of such fertilizers to adult palms at the above rate. These have prompted Government programs to increase fertilizer use in coconut lands.

In the case of young palms Uexkull (1975) reported that "....depending on the natural fertility of the soil (moisture and temperature), unfertilized palms come into bearing 8-12 years after planting. Full bearing is reached at about 16-20 years. If properly fertilized and maintained, palms can come into bearing only 4-6 years after planting and may reach the full bearing age at 9-11 years. The equivalent of 5-7 additional annual harvests may therefore be gained through use of fertilizer". Similar periods of additional annual harvests as reported by Uexkull (1975) could perhaps be expected in Sri Lanka.

1.3 Government Programme to Increase Coconut Production

Government of Sri Lanka in an effort to increase production as well as to improve the conditions of coconut lands, inaugurated a coconut rehabilitation scheme in 1956 consisting of two parts: (a) filling vacancies in planted areas and replanting low-yielding palms and areas with senile palms, with selected high yielding varieties of coconut seedlings, provided at a subsidized rate by the Coconut Research

Institute and (b) improving yields of coconut lands by the application of fertilizer provided under the Fertilizer Subsidy Scheme.

As compared to the subsidies given for tea and rubber replanting, the subsidy in coconut offsets only a minute fraction of the cost of replanting, especially when the implicit cost of foregoing output for several years while the newly planted seedlings are maturing is taken into account. With regard to this it may appear that if other costs of replanting are met, the replanting scheme would be much more attractive than at the present.

Under the fertilizer subsidy scheme, fertilizers are issued at a subsidy of 1/3 the cost of fertilizer to owners of coconut lands of 20 acres and over in size. The smallholders are provided fertilizer under this scheme at a subsidy of ½ the price of fertilizer. The lower limit of land or number of palms for which a fertilizer permit is issued was reduced from ½ an acre to ¼ acre or 60 palms to 30 palms with effect from 1972.

Apart from providing fertilizer at a subsidized rate, arrangements are also made at present by the Coconut Cultivation Board to promote the use of fertilizer by smallholders, by reducing transport costs and the difficulties of obtaining the fertilizer requirement in time. To this end the above Board has established fertilizer stores in some of the main coconut growing areas of the island such as Chilaw, Kuliyapihya, Viyangoda and Ambalangoda.

The response to the Coconut Fertilizer Subsidy Scheme since its inception has been considered encouraging. The quantity of fertilizer used prior to the introduction of the scheme was 10 to 12 thousand tons per annum. From 1956 to 1964, the quantity of fertilizer issued increased steadily to 48 thousand tons, and a total of Rs.49 million was paid in the form of subsidy during that period. The quantity used showed a further progressive increase up to about 60 thousand tons in

1970/71 (see Table 1.4). The drop in fertilizer use from 1972 onwards has been attributed to the uncertainty over the ceiling on land even though the price of coconut showed an improvement in 1973/74.

However though the quantity of fertilizer used has shown a big increase, this has not been matched by a corresponding increase in national production. Further study on this is necessary to isolate the factors which have produced this situtation.

1.4 Fertilizer Response Studies on Coconut

In this situation where a great deal of attention is focussed on short term methods of increasing coconut production, prinicpally through higher level of fertilizer use, it becomes important to investigate carefully the nature of the response of coconut to fertilizer usage. This is necessary if optimal fertilizer policies are to be implemented.

In short-term crops a large number of studies have been carried out on fertilizer response and methodology of the economic analysis is well developed. Because of the shorter time involved it is quite easy for an experimenter to obtain the required type and amount of data in short term crops.

Work done on long-term perennial crops on fertilizer response aspects are rare and a complete study on such crops needs data on temporal aspects as well, apart from the basic data on yield response. The response studies on long-term perennial crops are therefore complicated.

In this study a particular set of experimental data for coconut in Sri Lanka is analysed with a view to providing information that is normally not available from conventional type of analysis.

1.5 Description of the Experiment

Coconut is cultivated in a wide range of agroclimatic regions and soil types. The size classes of coconut holdings are many and, associated with them are a wide range of agronomic and management conditions.

The wide spacing (normally 26 feet) needed for the coconut palm makes it necessary for it to have larger plot sizes, for the experimental data to be statistically viable. Jochim (1934) showed that an 18 or 20-tree plot would be generally suitable for field trials with coconut. This makes the area required for a given experiment considerably large.

Because of the larger plot sizes and the uniformity in agronomic and management conditions needed, it appears that almost all the field experiments on coconut have to be conducted in larger coconut holdings.

The data that are used in the present study are obtained from an experiment conducted at the Coconut Research Institute (CRI) of Sri Lanka on a soil type consisting of a sandy loam overlying lateritic gravel, which is typical of a large portion of the main coconut growing area - the North Western Province of Sri Lanka. The average rainfall of the region is 60-80 inches and is comparatively well distributed throughout the year.

This experiment was primarily intended to supply information on the effect of common nutrients: nitrogen (N), phosphorus (P) and potassium (K) and the data were recorded for a period of 30 years (1935-1965).

The basic design of this experiment was a 3x3x3 factorial arrangement for nitrogen, phosphorus and potassium, each at 3 levels.

The plots in this experiment were arranged in blocks of 9 plots, with two replications, making 54 plots in all. Each plot covered approximately 0.273 acres and included 18 bearing palms planted at the average spacing. There were guard rows consisting of one row of palms between plots.

The manurial scheme which was originally adopted was modified in 1951 with respect to the potassium treatment, because it was observed that the potassium deficiency in the K_o series of plots was vitiating the experiment and endangering the life of the palms. Table 1.5 gives the original and the modified manurial schemes.

TABLE 1.5

RATES IN POUNDS PER ACRE AND CODED LEVEL OF N, P AND K USED IN FORMING TREATMENT COMBINATIONS FOR THE FACTORAL DESIGN

	N		P		K (1935-1950)		K (1950-1965)	
Level	Rate lbs/palm	Coded Level	Rate lbs/palm	Coded Level	Rate lbs/palm	Coded Level	Rate lbs/palm	Coded Level
LOW	nil	-1	nil	-1	nil	$-\frac{3}{2}$	.75	$-\frac{1}{2}$
MEDIUM	0.5	0	1.0	0	0.75	$-\frac{1}{2}$	1.50	$\frac{1}{2}$
HIGH	1.0	1	2.0	1	1.50	$\frac{1}{2}$	2.25	$\frac{3}{2}$

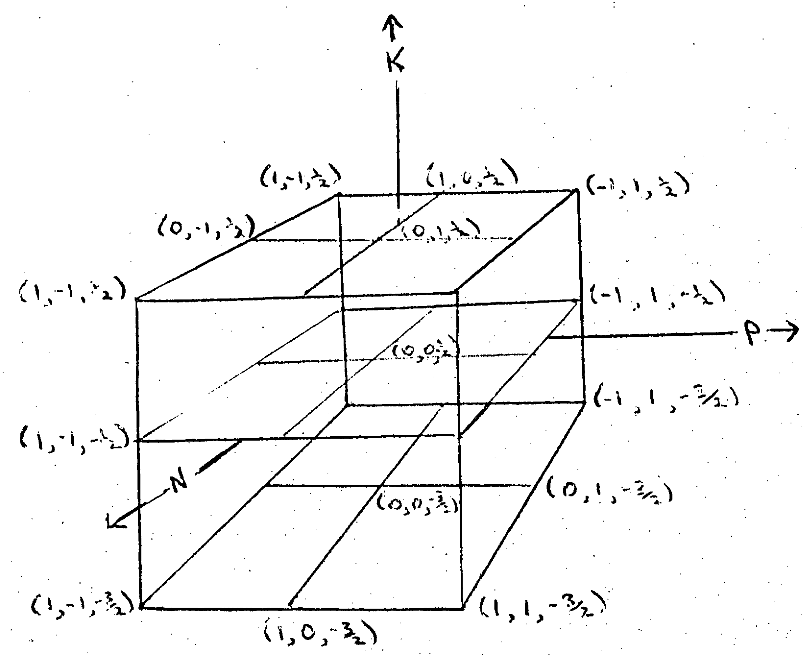
The fertilizer applications were made in alternate years in months of November. Weed control in the experimental plots was carried out once a year by not less than two harrowings. No cattle were allowed to graze.

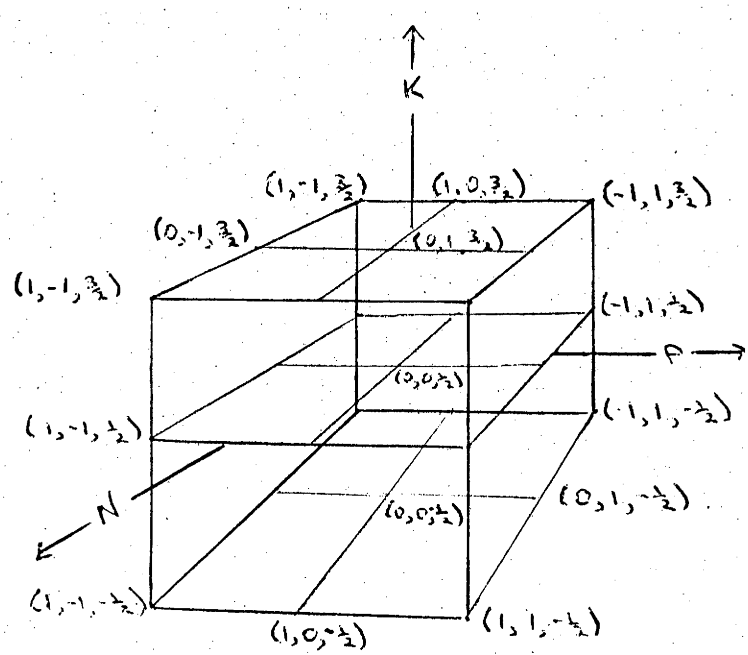
An inflorescence takes about 2 years to reach maturity from the time of emergence of it. Under average conditions inflorescences open successively at approximately four weekly intervals. Consequently harvesting is a continuous process throughout the year. The usual practice is to harvest ripe nuts at bi-monthly intervals and this practice was followed in this experiment.

The copra yields considered in this study were estimated using the conversion factor estimated by Peris (1935). He found that a conversion factor of 32% applied to the husked nut, gave a satisfactory estimate of copra content.

In addition to records of nuts, and the weight of copra for each individual plot, detailed records have been kept of the number of bunches, female flowers formed, number of immature nuts fallen, and analysis have also been made to determine the potash content of husks and the coconut

Fig.1.3.b CODED LEVELS OF N P K (1951-1965).





* The dots represent nutrient combinations. To avoid visual confusion only a few combinations are marked in this figure.

water.

The arrangement of treatment combinations during the periods 1935-1950 and 1950-1965 are illustrated in Figure 1.3.

Leaf analysis for this experiment was carried out only in its 30th year, and the results of it are presented in Table 1.6.

TABLE 1.6

ANALYSIS OF LEAF (14th LEAF) SAMPLES FROM
THE EXPERIMENTAL PLOTS
(% ELEMENTS ON OVEN DRY BASIS)

TREATMENT	N	P	K
N_o	1.91	0.129	0.489
N_1	1.93	0.128	0.460
N_2	1.94	0.124*	0.429
P_o	1.90	0.116	0.546
P_1	1.93	0.130**	0.445**
P_2	1.96	0.134**	0.387**
K_1	1.89	0.122	0.269
K_1	1.96**	0.129**	0.450**
K_3	1.94*	0.129**	0.659**

* significant at .05, ** significant at .01

Source: Ceylon Coconut Quarterly, Vol.XVII, 1966.

1.6 Value of the Data

The fertilizer response experiment described in section 1.1 could be utilized to extract agronomic information needed for economic analysis. Basically the data generated from the experiment could be utilized for economic analysis since it is derived from an experiment where there was sufficient variation in the input levels (3 levels) thus enabling to detect non-linearity if it is present.

Such factorial experiments are particularly pertinent to the generation of physical response data suitable for the estimation of response functions. In contradistinction to data generated from classical experimental designs such as randomized blocks, Latin Squares etc, the factorial experimental designs relate to the arrangement of treatments relative to one another and not to the positioning of the experiment and hence to the observations making these designs more suitable for fitting response functions. Furthermore particular stress can be given to data generated from factorial designs because of their greater relevance for response function estimation.

The generation of experimental data for short term crops is fairly easy because it is less time consuming, the cost involved is low compared to perennial tree crops and the experimenter is capable of reducing the unexplained variation considerably. Moreover replication of such experiments over space is also quite easy. Due to these reasons the agricultural economic work on fertilizer response aspects of short term crops are many.

Similar work on perennial tree crops are meagre. Out of many reasons it would appear that the lack of sufficient agronomic information such as response to nutrients over the productive life of the crop, etc based on experiments is a major cause for it. Unlike for a short term crops, conducting agronomic experiments in coconut or any perennial tree crop is difficult in many ways. This is due to:

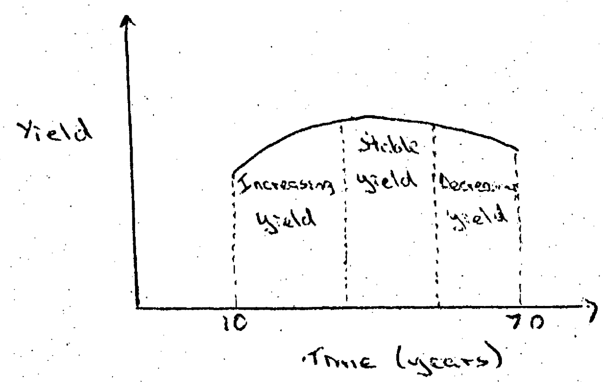
a) Longer time period involved

b) Need for larger areas planted with the crop with uniform age structure, genetic characteristics and under uniform soil type and,

c) The higher costs involved.

The widely cultivated typica form of the Typica variety of coconut (the variety and the form used in the experiment under consideration) for instance has a productive life span of 50-60 years. Just as any other crop, the coconut palm also may in general be expected to show a phase of increasing yield, a stable yield and decreasing yield (see Figure 1.4). The duration of these phases up to a certain limit depend on climatic, soil, nutrient factors etc (see Chapter 3 also). Published work on the duration of these phases are lacking.

FIGURE 1.4   PHASES OF PRODUCTION



Thus if an experiment on a perennial tree crop such as coconut is conducted it is important to capture at least two of the production phases if not all. If the latter two production phases are captured, it would provide more information needed for many economic studies apart from its value to an agronomist. Formulation of optimal replacement policies, formulation of fertilizer policies are some of the economic studies that can be carried out with such data. Thus it appears that obtaining valuable data from a perennial tree crop such as coconut is a longer time consuming process that it is for a short term crop.

The experiment conducted by the Coconut Research Institute using the typica form of the Typica variety of coconut provides nutrient response data for 30 years. Experimental evidence or any other information based on observations are not available on the length of each production phase. Assuming that each production phase is about 20 years, the data in hand would provide information on response pattern of at least two phases (2nd and 3rd).

Whether the production phases are of equal length or of unequal length or whether a particular nutrient combination could prolong increasing or constant production phase or whether the decreasing phase could be altered so that the decrease is at a decreasing rate are all agronomic information that would be valuable if it can be extracted from the present set of data to aid in the formulation of fertilizer policies for coconut and to conduct other agricultural economic studies.

1.7 Objectives of the Present Study

Specification of response functions is an essential primary step in economic analysis. Unlike for a short term crop, the specification of response functions for a perennial crop is difficult. This is because of many factors which cause the variability in response over time. Carry-over effects, age effects are some factors responsible for such variability (see Chapter 2 for details).

The task of specifying response functions becomes further complicated when the required information on temporal effects are not available

The experimental data available at hand provides the basic information needed for the specification of response functions. However, the information such as carry-over of nutrients in plant tissues and soil etc, that are needed for direct incorporation of temporal effects in a response function are not available for the present study.

The objective of this study is to find out how far the temporal effects are treatment specific and to use this information as far as possible to provide sufficient background for the formulation of fertilizer policies.

It will also be shown how, a response function could be derived using the data at hand.

The areas of improvement needed in such response function studies in order to utilize response data for economic analysis will be pointed out.

This analysis thus seeks to extend the agronomic analysis that was carried out by Eden, Gower and Salgado (1963) for the 1st 25 years of the experiment. In the present study the data available in subsequent years is also utilized. The analysis carried out by Eden *et al*, is described and its limitations particularly in relation to temporal effects is discussed in the next chapter.

CHAPTER 2

ANALYSIS WITHOUT TEMPORAL EFFECTS

2.1 Analysis carried out by Eden, Gower and Salgado

Eden, Gower and Salgado (1963) carried out analysis of the observations on, the number of nuts and the weight of copra of the individual years. The data on nut yields were analysed for the 22 year period from 1936-1957 and the data for copra were analysed for the 23 year period from 1935-1957.

The main objective of their analysis was to find out the response of each yield parameter for the nutrients N, P and K. Apart from this, analysis was also carried out on the mean response for the 28 years and the effects of subsidiary factors influencing the manurial response.

Analysis of variance as a 3x3x3 factorial has been carried out for each year to find out:

a) the general response to nutrients N, P and K,

b) the additional response to nutrients N, P and K,

c) the interactions between general and additional responses,

d) the interactions between general responses and

e) the interations between additional responses.

The general response refers here to the average of response to the single and double dressings and is given as:

$$X' = \tfrac{1}{2}(\bar{X}_1 + \bar{X}_2) - \bar{X}_o$$

where X refers to any particular nutrient.

The additional response refers to the additional response to a double dressing over that to the single dressing and is given as:

$$X'' = \bar{X}_2 - \bar{X}_1$$

The mean over all years and linear and quadratic regressions on years have been found for each plot. Each of these data has been analysed in the same manner as the data for individual years to provide tests of significance for mean effects and trends.

2.1.1 Results for number of nuts

The number of nuts showed definite response to a single dressing of N. This however showed a significant decline during the latter part of the period. Response to double dressing of N was not significant except in one year.

The response to both single and double dressing of P were below the significance level. The latter part of the 22 year period however showed a positive mean general response and a significant positive trend to their response.

The effect of K on nut number was highly significant at both dressings. A decline in the response to K however was observed from 1951 onwards. (See Tables 1 and 2 - Appendix B).

Significant interactions for both single and double dressings of N and K were observed. (See Table 5 - Appendix B).

2.1.2 Results for copra

High positive response for N was shown for the first eight years of the experiment. However it was only during two years that the response was significant at 5% level (See Table 3 and 4 - Appendix 3B). After a period of transition following the change of K manuring, the single dressing of N showed a very low negative response. The double dressing of N showed no evidence of significance. Taken as a whole the analysis showed that the benefits from N manuring was small or non existant.

Response to P is even less consistant than those to N. The response to the single dressing over the whole period was negative and the double dressing showed positive response. However both were a fraction of their standard error and on the whole P appeared to have no appreciable effect.

K on the other hand showed a large and positive response for the single dressing and even the double dressing showed substantial positive response. Eden et al analysis also indicated that the response for single dressing of K built up to a maximum in 1951 and declined till the response showed signs of stability. A similar decline around 1951 was seen for the double dressing of K as well. The same pattern followed in the response of nut number of K.

Eden et al analysis also showed that the response to K as far as copra was concerned occurred within a very short period of about one year.

The presence of an appreciable amount of residual effects of K was defected by Eden et al, by comparing the additional response before and after the K change.

In general the Eden et al analysis showed that the responses were similar for the number of nuts and copra with the exception that N application increased the number of nuts but not the copra yield. P had little effect on both yield parameters. With regard to K application large and increasing responses to the first level of K and smaller but still appreciable responses to additional level of K were obtained.

Their analysis also indicated that, the manufactural applications did little to raise the absolute level of yields over the 25 year period.

The only detectable interaction was that between N and K.

Analysis of variability for the whole period was carried out by Eden et al by investigating the mean, linear and quadratic components for 1935-51 for copra and 1936-58 for number of nuts. From this it was concluded that K is the only one showing substantial additional variation over time.

2.1.3 Effect of subsidiary factors

The timing of manuring and the weather conditions prevailing during nut formation may be expected to effect the response from year to year. Also it could be expected that the biennial manufacturing would give rise to less copra in the blank year than the year following the application since the copra yield can be effected by nutrients within a short period of time. Eden et al, carried out analysis to find out whether these factors have any correlation to the fertilizer response.

With regard to biennial manuring they found that, the year following manuring gave on the average higher yields but the difference did not reach statistical significance.

A large variation from year to year in absolute yields was observed but no significant correlation was found between yields and seasonal rainfall.

2.2 Limitations for the Analysis

A number of limitations are seen in the above analysis which are primarily due to the deficiencies in the data generated and the lack of recognition of temporal effects.

Owing to these limitations, the analysis fails to separate out the 'pure nutrient effect' which is due to the nutrients alone and the temporal effects. As a result of this the information that are quite useful on manuring of continuous bearing perennial crops, such as the (a) age specific manuring (b) the fertilization to reduce the age induced decline in yield, (c) the importance of carry-over nutrients etc, are lacking.

The important factors associated with time that are important in the nutrient response study of a perennial crop are (i) the nutrient response lag (ii) the nutrient carry-over in the soil, (iii) the nutrient carry-over in plant tissues and (v) the change in capacity of the crop to respond with ageing.

These are discussed in some detail on the following sections.

2.2.1 Nutrient response lag

Due to the biological processes associated with the utilization of nutrients, a certain time period elapses before a crop manifests the effect of a change in nutrient level. For a particular crop this time period may vary, depending on the nutrient status of the soil, weather conditions, etc.

If the time period between the nutrient application and manifestation of effects of it, "the nutrient response lag", is L years, then the yield (Y_t) in year t should be matched with the nutrients in year (t-L), (i.e. $X_{(t-L)}$).

This relationship can be modelled as:

$$Y_t = f(X_{(t-L)})$$

In multipoint input, multipoint harvest crops such as coconut, the concept of response lag becomes important particularly if nutrient input is varied each year. If the input levels are not varied (i.e., the same quantity of nutrients applied each year), $X_{(t-L)}$ will be equal to X_t and the above response function could be written as $Y_t = f(X_t)$.

Figure 2.1 shows the development process of a bunch of coconuts from the initial inflorescence stage. The 2½ to 3 year long development process consists of a number of phases. The flower differentiation phase is the earliest phase in this process, at which an appreciable response to a change in nutrient level can be noted.

The inflorescence goes through a number of subsequent phases over about two years ending in a bunch of coconuts. The number of nuts in the bunch normally appears to bear a positive correlation to the number of female flowers produced*, which in turn is governed by the

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* It is observed that a certain percentage of the female flowers are shed within a few weeks of emergence of the inflorescence. The percentage of the flowers that remains in the inflorescence is governed by the genetic potential of the palm, climatic and nutritional conditions, efficiency of pollination and pathological conditions.

nutrient availability at the flower differentiation phase. Thus, it is clear that nutrients that are made available at the flower differentiation phase manifests these effects on the yield of coconut after a lag of about 2 years (see Salgado, 1941, Fremond, 1963, Smith, 1973). This time period can be considered as the nutrient response lag in coconut for the purposes of deriving nutrient response function:

$$Y_t = f(X_{t-2}) \qquad (2.2.1)$$

where Y_t is yield of coconut in year t and $X_{(t-2)}$ is the nutrients applied in year (t-2.) In analysing the present set of data, it is not necessary to match Y_t with $X_{(t-2)}$ since the same quantity of nutrients were applied each year (see foregoing discussion).

2.2.2 Nutrient (fertilizer) carry-over in the soil.

Nutrient carry-over effect may occur from one production period to another, if the application of nutrients within one production period is not completely utilized in that period. Thus the amount of nutrients available to a plant in any given period depends on the applications of nutrients in previous periods as well as the application in the current period. The yield in the current production period therefore will be a function of both, current application of nutrients and the nutrient residues carried over from previous periods.

$$Y_t = f(X_t, R^{(s)})$$

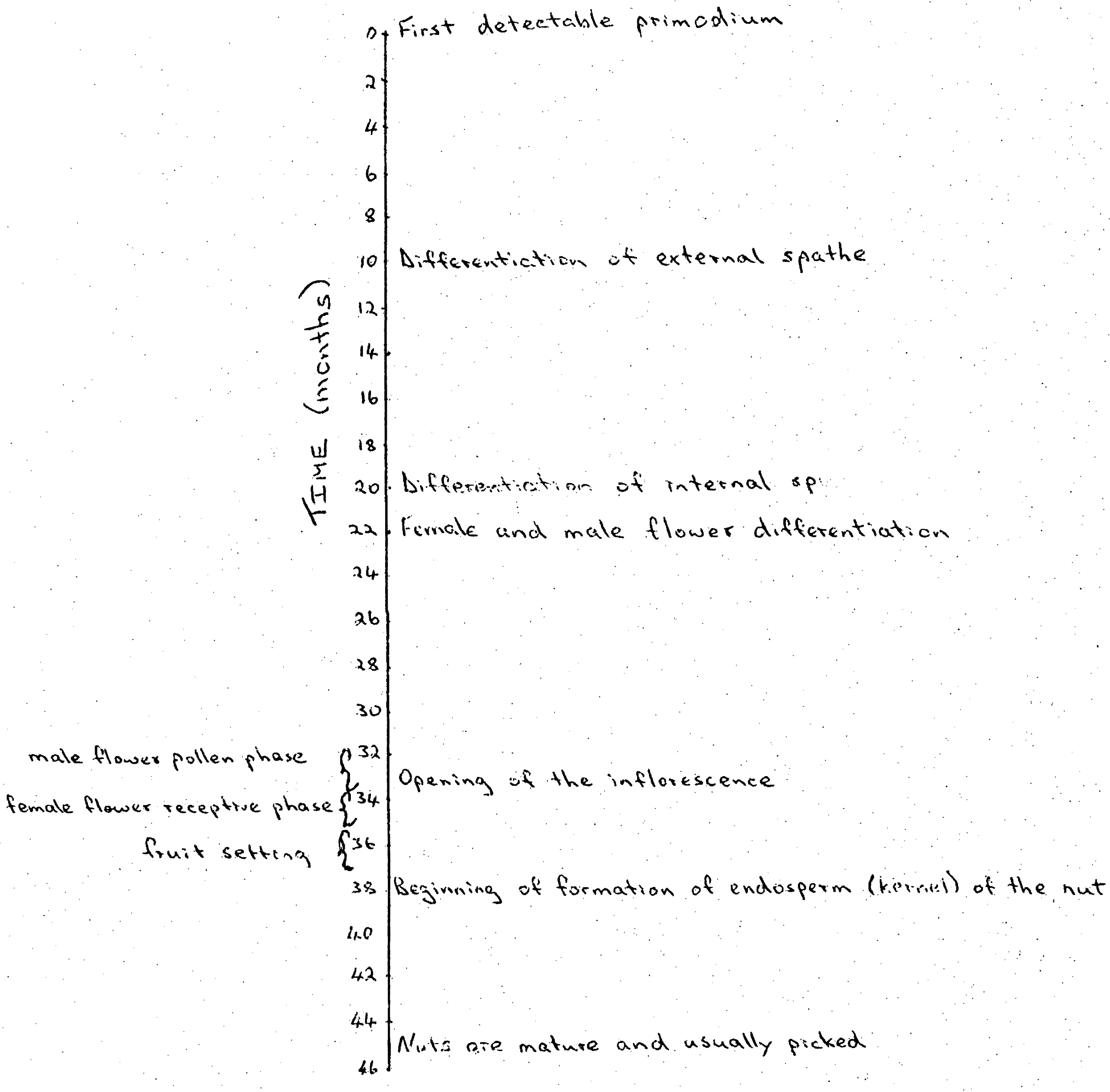
where Y_t is yield in year t

X_t is nutrients applied in year t

$R^{(s)}$ is the residual nutrients carried over from previous applications (i.e. before the year t) and s refers to soil.

The above function could be modefied for coconut to allow for the two year nutrient response lag as:

Fig. 2.1 DEVELOPMENT OF A BUNCH OF NUTS



$$Y_t = (X_{(t-2)}, R^{(s)}_{(t-2)}) \qquad (2.2.2)$$

where $X_{(t-2)}$ and $R^{(s)}_{(t-2)}$ are nutrients applied and the residual nutrients carried-over from previous years respectively.

The carry-over effect is likely to vary with soil type, climate, frequency and level of nutrient application. If the carry-over effect is significant in the agronomic sense, then its consideration may influence the policy for optimal application of fertilizer (Kennedy, Whan, Jackson and Dillon, 1973) and the determination of optimal fertilizer policies is considerably complicated.

Over the 30 years of period of the 3x3x3 NPK factorial experiment under consideration, P showed no appreciable response (Child, 1974). The lack of response to phosphorous as reported to be observed in the above experiment is not universal and is attributed to the residual effects of heavy dressings of bone meal which the soils of the experimental area are reported to have received before the land was acquired by CRI for experimental purposes (Eden, Gower and Salgado, 1963).

In other trials in Sri Lanka on poor latosols containing only traces of available P, large responses were obtained from application of 12 kg of P per palm. In one such experiment the soil reserve potential soon built up to a point at which discontinuance of P applications did not lead to a reduction of crop for a least 5 years (Child, 1974). This further illustrates the importance of residual nutrients in the nutrient response of coconut palm.

Cooke (1952) believes that besides phosphoric acid, potash also accumulates in the soil, but nitrogen has no such effect. The lack of response for N for a higher dose of 1.0 lbs of N per palm since 1938 and for a lower dose of 0.5 lbs of N per palm since 1942 for the 3x3x3 NPK experiment* may have been caused by the accumulation of N in the soil

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* This is the experiment considered in the present study. It was started in 1936.

under the cultivation regime adopted in the experimental area, which rendered further applications in the form of artificals unnecessary.

2.2.3 Nutrient carry-over in plant tissues

In a perennial crop the yield in any given year t, could be appreciably affected by the nutrients released by the plant tissues in that year. In such a case the nutrients available in the plant system for the reproductive processes (or any other process) in that year would be:

$$F_{(t-2)} = X_{(t-2)} + R^{(s)}_{(t-2)} + R^{(T)}_{(t-2)}$$

where $R^{(T)}$ is the residual nutrients released from the plant tissues and made available in the year (t-2). The other parameters are as described in the preceeding sections.

The yield function 2.2.2 given in the proceeding section could be modified to allow for nutrient carry-over in plant tissues as:

$$Y_t = f(X_{(t-2)}, R^{(s)}_{(t-2)}, R^{(T)}_{(t-2)} \qquad (2.2.3)$$

Data on the proportion of absorbed nutrients that is stored each year, the allocation of nutrients to different storage tissues, frequency of release of stored nutrients, the pattern of utilization of nutrients which get mobilized, from storage tissues, etc, and the conditions governing each of the above are lacking for the coconut palm. Therefore estimation of carry-over nutrients in coconut involves a number of problems.

2.2.4 The variability in response with aging

A perennial crop would show variability in response over time, to the same quantity of nutrients applied at regular intervals and under average conditions. A part of this variation could be explained by the nutrient carry-over effect in the soil, and the plant tissues. The manner in which these carry-over effects could be allowed for in a response function is discussed in section 2.2. and 2.2.

The variability of the capacity of the crop to respond to nutrients or the variability of response with ageing would also be contributary to the variability in response over time. This could be summarised in a functional form as:

$$\left.\begin{matrix}\text{VARIABILITY IN RESPONSE}\\ \text{OVER TIME}\end{matrix}\right\} = f\left\{\begin{pmatrix}\text{VARIABILITY BROUGHT ABOUT}\\ \text{BY CARRY-OVER EFFECTS}\end{pmatrix}, \begin{pmatrix}\text{CHANGE IN CAPACITY TO}\\ \text{RESPONSE WITH AGEING}\end{pmatrix}, \begin{pmatrix}\text{OTHER FACTORS ASSUMED}\\ \text{TO BE NON-SIGNIFICANT}\\ \text{IN THIS STUDY}\end{pmatrix}\right\}$$

Since the variability in capacity to response with ageing is brought about by the time factor it could be explained in an algebraic form in a response function by incorporating a time variable.

Response function 2.2.3 could therefore be modified as:

$$Y_t = f(X_{t-2}, R^{(t)}{}_{(t-2)}, R^{(T)}{}_{(t-2)}, t) \qquad (2.3.4)$$

where $_t$ is the time factor. The other parameters are as described in proceeding sections.

The yield of any given year reflects pure nutrient effect and temporal effects. Therefore when analysing the yield of a particular year to find the effect of N, P and K the temporal effects need to be considered. In the Eden et al, analysis it appears that the yield in a given year was considered as a function of $X_{(t-2)}$ alone. This gives rise to overestimation of the response to nutrients when age effects are positive and under estimation when age effects are negative.

Similarly if residual effects are high, this would lead to over estimation of the effects of nutrients.

Thus inclusion of temporal effects has many advantages. Apart from other advantages it would help to obtain age specific nutrient requirment of the crop and the information on the quantity of nutrients that will be needed when the carry-over effects are substantial. Eden et al have considered temporal aspects only through an analysis of trends.

2.3 Need for More Data

Some of the temporal effects could be allowed for in the analysis directly and quite simply without any additional experimental data. However as shown in the preceeding section the direct incorporation of carry-over effects (or to test for their effects) in soil and plant tissues we need data collected by soil testing and plant tissue analysis conducted in conjunction with the fertilizer response experiments.

Such data are not available for the present analysis perhaps because the importance of the temporal effects was not realized at the time this experiment was started.

A number of different procedures are available which could be utilized for the indirect estimation of carry-over nutrients in the soil when experimental data are not available. An example is the estimation of carry-over nitrogen in perennial grass.

When soil analytical data are not available it would be possible to estimate them using a carry-over function. Stauber and Burt (1973) estimated production functions for perennial grass, incorporating the nitrogen carry-over effects estimated using a carry-over functions*. They indicated that the crux of the method is to specify a comprehensive, logically consistent model of both yield response and nitrogen carry-over such that the only observed measurements required are applied nitrogen and grass yield.

The estimation is through an iterative method using difference equations.

This method could be extended reasonably well to estimate the carry-over of a number of nutrients under a larger number of climatic and soil

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* The carry-over relationship is estimated implicitly through yield response as opposed to direct measurements on nitrogen.

factors. However in such an instance specification of a carry-over function to capture all the climatic and soil factors and their interactions with the nutrients will be a difficult task.

Though the required subsidiary data is lacking, due to the value of the time-series data that is available, a detailed graphical analysis of the temporal effects is attempted in the next chapter.

CHAPTER 3

EMPIRICAL ESTIMATION OF NUTRIENT RESPONSE

Based on the discussion on Chapter 2, the yield of coconut in any given year can be expressed as:

$$Y_t = f\left\{X_{(t-2)}, R^{(s)}_{(t-2)}, R^{(T)}_{(t-2)}, t\right\} + \text{error.}$$

where Y_t is the yield in year t;

$X_{(t-2)}$ the nutrients applied in year (t-2);

$R^{(s)}_{(t-2)}$ the carry-over nutrients available in soil,

$R^{(T)}_{(t-2)}$ the carry-over nutrients available in plant tissue for development processes and,

t is the time factor representing the change in capacity of the palm to respond to nutrients with ageing.

For the present analysis data on nutrient carry-over are not available and hence cannot be incorporated directly in a response function. This however will be allowed for in the response function by introducing lag effects.

A proper appreciation of the development process of a bunch of coconuts is necessary in order to justify the use of such a procedure (use of lag effects) to allow for carry-over nutrients and to specify the actual form of it.

3.1 Nutrient Utilization and Correlation of Successive Outputs.

The bunches of coconuts come into maturity successively under average conditions at approximately four-weekly intervals. Each bunch takes 2-3 years for the development process, from the principal stage.

The development process can be divided into several phases, and of these, there are at least three phases which show active response to major nutrients N, P and K available in the soil-palm system*, subsequently giving rise to significant effects on output such as, the

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* Nutrients available in soil-palm system are those applied to the soil, the carry-over nutrients in soil and the carry-over nutrients in plant tissue.

number of nuts, the copra out turn etc, in a bunch of coconut.

The phase A (See Figure 3.1), governs the number of nuts produced in each bunch. The number of female flowers produced during this phase depends on the availability of N and P. Since the number of female flowers in an inflorescence appears to be directly correlated to the number of nuts in a bunch, this phase can be considered as the most important phase out of the three phases shown.

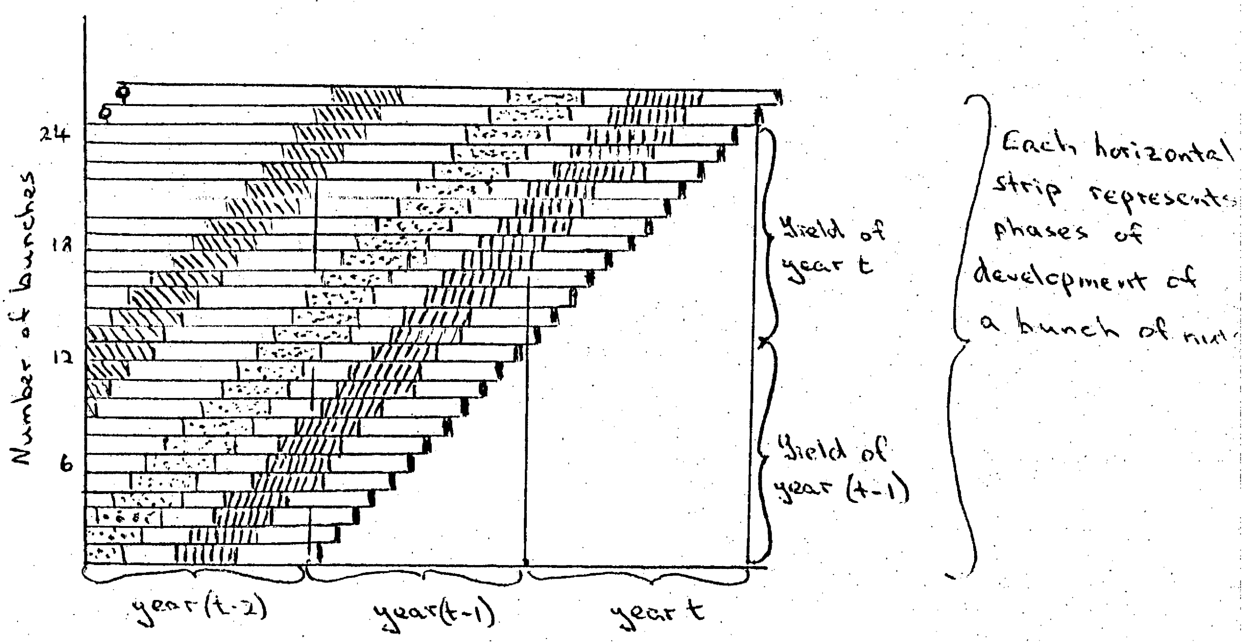
Phase B governs the proportion of female flower setting. If the availability of K is high, then the percentage setting of female flowers is improved and a higher percentage of the female flowers that are produced in the phase A will be developed into nuts.

Phase C governs the copra out-turn. If there is sufficient availability of K, then the copra out-turn of the developing nuts will be increased during this phase.

As can be seen from Figure 3.1, due to the continuous development process, each of these phases overlap one another. Therefore in any given period of time (say year t-2 as illustrated in Figure 3.1) these similar phases of development would compete with one another for the same kind of nutrients that are available in the soil-palm system. As for example phase A from 12 bunches of coconut that is within the year (t-2) will compete with each other for N and P. Similar competition can be expected from phases B and C. Thus the yields of successive harvests of bunches would be correlated. Copra out-turn from bunches of coconut harvested in year t-1 will be correlated to the copra out-turn from bunches of coconut harvested in year t. Similarly the number of nuts harvested in these two years also will be correlated.

There is also competition among different types of phases for the same kind of nutrients. Phase A compete with phases B anc C for K. Therefore it could be expected that there would be correlation between the yield parameters such as number of nuts and the copra out-turn in

Fig.3.1 PHASES OF DEVELOPMENT OF BUNCHES OF NUTS



o Developing flower primodium

Phase A - nitrogen + phosphorous affect production of female flowers

Phase B - potassium affects setting of female flowers

Phase C - potassium affects copra out-turn

Phase of maturity of a bunch of nuts

* This figure shows only those phases which are considerably affected by N, P and K.

any given year and its successive year (or years). Copra yield in year (t-2) for instance will be correlated to the copra yield in year t. The number of nuts in year (t-2) will be correlated to the number of nuts in year t.

3.2 Analysis for Overall Mean Response and Temporal Effects

The two output parameters, nuts and copra are analysed in the present study to separate the effects of overall mean response due to N, P and K and the temporal effects.

Since only two plots received any one combination of N, P and K (treatments were replicated twice), the overall mean effect of the nutrients and the temporal effects of the nutrients on yield in each plot would be plot specific (see the graphical analysis in Chapter 4). First therefore a plot by plot analysis of the data is carried out to separate these effects.

Let $Y^{(1)}_{t,k}$ and $Y^{(2)}_{t,k}$ be the observed yields of nuts and copra respectively in year t and plot k. The model used is based on two equations. First for yield of nuts in year t,

$$Y^{(1)}_{t} = \alpha^{(1)}_{o,k} + \alpha^{(1)}_{1,k}t + \alpha^{(1)}_{2,k}t^2 \; \phi_{11,k}Y^{(1)}_{(t-1)} + \phi_{12,k} Y^{(2)}_{(t-1)} + \Delta^{(1)}_{1,k}X_{1,t} + \Delta_{2,k}X_{2,t} + \varepsilon^{(1)}_{t,k} \qquad (3.1a)$$

k = 1-54 and t = 1-30 where t = 1 in 1935 and t = 30 in 1965.

$\alpha^{(1)}_{o,k}$ represents the overall mean response due to N, P and K on nut yield for plot k over the 30 year period.

$\phi_{11,k}Y^{(1)}_{(t-1)} + \phi_{12,k}Y^{(2)}_{(t-1),k}$ represents the carry-over effects of all kinds from year t-1 to t.

The carry-over effects from year t-2 to year t is not included since the results obtained from a preliminary analysis of the data showed that second order lags were not significant.

$\phi_{11,k}$ and $\phi_{12,k}$ are the plot specific coefficients for lagged variables of the two output parameters.

The effect of carry-over nutrients in the soil and that in the plant tissues however cannot be studied separately.

$\alpha^{(1)}_{1,k}t + \alpha^{(1)}_{2,k}t^2$ represent linear and quadratic time trends to allow mainly for the change in capacity of palm to respond to nutrients with ageing.

$\alpha^{(1)}_{1,k}$ and $\alpha^{(1)}_{2,k}$ are the plot specific coefficients of the time trends.

$\Delta^{(1)}_{1,k}X_{1,t}$ allows for the modification of the level of potassium in the year 1951 (see Chapter 1). The dummy variable X_1 was incorporated in the following way

$$X_1 = \begin{matrix} 0, \text{ for years 1935-1950} \\ 1, \text{ for years 1951-1965} \end{matrix}$$

and $\Delta^{(1)}_{1,k}$ is the coefficient of the dummy variable.

$\Delta^{(1)}_{2,k}X_{2,t}$ allows for the alternate years of fertilizer application. The dummy variable X_2 was incorporated in the following way.

$$X_2 = \begin{matrix} 0, \text{ odd numbered years commencing with 1935} \\ 1, \text{ even numbered years commencing with 1936} \end{matrix}$$

and $\Delta^{1}_{2,k}$ is the coefficient of the dummy variable

$\varepsilon^{(1)}_{t,k}$ is the error term.

Similarly the equation for the observed yield of copra in year t can be given as:

$$Y^{(2)}_{t,k} = \alpha^{(2)}_{0,k} + \alpha^{(2)}_{1,k}t + \alpha^{(2)}_{2,k}t^2 + \phi_{21,k}Y^{(1)}_{(t-1),k} + \phi_{22,k}Y^{(2)}_{(t-1)}$$
$$+ \Delta^{(2)}_{1,k}X_{1,t} + \Delta^{(2)}_{2,k}X_{2,t} + \varepsilon^{(2)}_{t,k} \qquad (3.1b)$$

The results of the first stage of analysis are presented in Tables 3.1a and 3.1b.

3.2.1 Discussion of the results

The analysis of the yield functions 3.1a and 3.1b shows that a negative linear time trend and a quadratic time trend were present in majority of plots for the two yield components. For the nut yield, 13 plots showed that there is a negative and significant linear time effect and 12 plots showed that there is a positive component of the

TABLE 3.1 COEFFICIENTS OF THE EQUATION 3.1a AND THEIR T-STATISTICS (NUT YIELD)

	$\alpha^{(1)}_{1,k}$		$\alpha^{(1)}_{2,k}$		$\phi_{11,k}$		$\phi_{12,k}$		$\Delta_{1,k}$		$\Delta_{2,k}$	
Treatment	Value	t-stats	Value	t-stats	Value	t-stats	Value	t-stats	Value	t-stats	Value	t-sta
1 $N_0P_0K_0/k_1$	-10.1	-3.54*	1.05	5.83*	1.19	3.36*	-1.99	-2.33*	66.5	1.35	-38.1	-1.0
2 $N_0P_0K_1/k_2$	-10.9	-3.36*	0.55	2.67*	1.11	2.70*	-1.61	-2.04*	138.0	2.46*	-19.0	-0.3
3 $N_0P_0K_2/k_3$	-17.0	-4.62*	0.41	1.72	1.17	2.94*	-1.66	-2.25*	101.0	1.59	-15.0	-0.2
4 $N_0P_1K_0/k_1$	0.26	0.07	0.52	2.35*	1.11	2.23*	-1.55	-1.67	-18.5	-0.31	-44.9	-0.8
5 $N_0P_1K_1/k_2$	-9.03	-2.07*	0.29	1.04	1.66	4.31*	-3.18	-4.18*	18.8	0.25	-192.0	-2.3
6 $N_0P_1K_2/k_3$	-0.27	-0.05	-0.02	-0.07	0.19	0.56	-0.05	-0.11	105.0	1.13	-106.0	-1.8
7 $N_0P_2k_0/k_1$	-5.78	-1.21	1.81	5.86*	0.86	2.81*	-1.33	-2.35*	72.2	0.87	-52.1	-0.8
8 $N_0P_2K_1/k_2$	-3. 5	-0.67	0.80	2.40*	0.95	2.11*	-1.49	-1.67	34.6	0.38	-67.1	-0.7
9 $N_0P_2K_2/k_3$	-8.26	-1.90	0.55	1.89	1.15	2.39*	-1.96	-2.00*	91.3	1.22	-380.0	-3.9
10 $N_1P_0K_0/k_1$	2.85	0.68	0.27	0.90	1.09	2.53*	-1.42	-1.96*	-62.8	-0.78	-152.0	-2.7
11 $N_1P_0K_1/k_2$	-14. 2	-3.01*	0.41	1.32	1.51	3.80*	-2.87	-3.36*	59.8	0.73	-58.9	-1.0
12 $N_1P_0K_2/k_3$	-10. 4	-2.53*	-0.47	1.78	1.26	3.28*	-2.17	-2.72*	-4.04	-0.06	-27.8	-0.5
13 $N_1P_1K_0/k_1$	-2.06	-0.42	1.15	3.51*	1.30	3.18*	-2.09	-5.32*	-54.3	-0.63	-51.1	-1.3
14 $N_1P_1K_1/k_2$	-8.26	-2.44*	0.38	1.72	0.99	3.03*	-1.32	-2.41*	-24.0	-0.41	22.4	0.6
15 $N_1P_1K_2/k_3$	-59.8	-1.28	0.46	1.53	1.76	5.51*	-3.21	-5.37*	55.9	0.69	-53.3	-0.6
16 $N_1P_2K_0/k_1$	-10.9	-2.35*	1.19	3.95*	1.98	7.88*	-3.94	-5.74*	78.0	0.97	-70.8	-1.0
17 $N_1P_2K_1/k_2$	-13.9	-3.13*	-0.16	-0.50	1.01	2.27*	-2.10	-2.63*	112.0	1.45	-84.8	-1.3
18 $N_1P_2K_2/k_3$	5.91	1.07	0.46	1.26	0.08	0.18	0.00	0.00	-94.4	-0.98	-10.4	-0.2
19 $N_2P_0K_0/k_1$	-15.9	-4.00*	1.24	4.84*	0.82	1.73	-0.08	-0.98	77.3	1.13	-90.2	-1.4
20 $N_2P_0K_1/k_2$	-0.41	-0.09	0.74	2.74*	0.13	1.64	0.09	0.13	-5.68	-0.08	-64.0	-0.9
21 $N_2P_0K_2/k_3$	-14.2	-3.22*	-0.31	-1.05	1.13	2.56*	-2.03	-2.44*	-8.38	-0.11	-56.5	-0.9
22 $N_2P_1K_0/k_1$	-12.6	-2.52*	1.58	4.88*	1.91	7.95*	-3.32	-5.84*	58.9	0.68	-188.0	-2.5
23 $N_2P_1K_1/k_2$	-9.45	-1.64	0.78	2.07*	0.69	1.44	-0.92	-1.07	26.5	0.26	-78.0	-0.8
24 $N_2P_1K_2/k_3$	-6.99	-1.56	0.56	1.94	0.74	1.96*	-0.84	-1.23	56.7	0.73	-61.2	-0.7
25 $N_2P_2K_0/k_1$	-8.32	-2.27*	1.83	7.83*	0.51	1.19	-0.69	-0.92	67.3	1.06	-95.3	-1.5
26 $N_2P_2K_1/k_2$	-6.78	-1.34	0.30	0.90	0.07	0.33	0.32	0.88	73.2	0.84	-325.0	-3.1
27 $N_2P_2K_2/k_3$	-9.55	-1.73	0.67	1.89	1.25	3.23*	-1.88	-2.68*	45.2	0.47	26.4	0.3

* Significant at 5% level.

TABLE 3.1b. COEFFICIENTS OF THE EQUATION 3.1b AND THEIR T-STATISTICS (COPRA YIELD)

	$\alpha^{(2)}_{1,k}$		$\alpha^{(2)}_{2,k}$		$\phi_{21,k}$		$\phi_{22,k}$		$\Delta^{(2)}_{1,k}$		$\Delta^{(2)}_{2,k}$	
Treatment	Value	t-Stats	Value	t-stats	Value	t-stats	Value	t-stats	Value	t-stats	Value	t-stat
1 $N_0P_0K_0/k_1$	-3.17	-1.32	0.44	2.83*	0.34	1.72	-0.64	1.61	12.7	0.31	9.72	0.44
2 $N_0P_0K_1/k_2$	-5.56	-2.41	0.33	2.11*	0.46	2.03*	-0.68	-1.57	104.0	2.57*	-8.55	-2.99*
3 $N_0P_0K_2/k_3$	-8.23	-3.02*	0.19	1.07	0.53	2.40*	-0.84	-1.99	76.9	1.63	-46.5	-0.17
4 $N_0P_1K_0/k_1$	-1.31	-0.51	0.34	1.97*	0.38	1.32	-0.52	-0.97	17.5	0.39	-1.83	-0.08
5 $N_0P_1K_1/k_2$	-3.76	-1.50	0.19	1.12	0.63	2.89*	-1.25	-2.89*	27.9	0.64	-55.2	-1.87
6 $N_0P_1K_2/k_3$	-1.47	-0.36	-0.09	-0.33	0.09	0.30	-0.17	-0.49	102.0	1.45	-30.4	-1.16
7 $N_0P_2K_0/k_1$	-5.25	-1.66	1.05	5.04*	0.37	1.31	-0.46	-0.93	76.4	1.39	-20.0	-0.68
8 $N_0P_2K_1/k_2$	-2.40	-0.71	0.52	2.35*	0.40	1.72	-0.69	-1.51	44.6	0.76	-19.6	-0.32
9 $N_0P_2K_2/k_3$	-2.99	-1.07	0.21	1.13	0.38	1.52	-0.71	-1.39	55.1	1.14	-104.0	-3.29*
10 $N_1P_0K_0/k_1$	-0.68	-0.21	0.25	1.17	0.44	1.61	-0.66	-1.05	28.2	0.51	-54.6	-2.13*
11 $N_1P_0K_1/k_2$	-7.29	-2.50*	0.29	-1.47	0.46	2.19*	-0.92	-2.03*	66.1	1.31	-10.8	-0.47
12 $N_1P_0K_2/k_3$	-4.92	-1.13	0.27	0.92	0.41	1.97*	-0.82	-1.94	17.8	0.24	-19.8	-0.58
13 $N_1P_1K_0/k_1$	-1.93	-0.67	0.64	3.33*	0.57	2.58*	-1.03	-2.33*	-11.4	-0.28	-13.9	-0.73
14 $N_1P_1K_1/k_2$	-5.06	-1.91	0.28	1.57	0.29	1.33	-0.46	-1.27	1.84	0.04	8.53	0.43
15 $N_1P_1K_2/k_3$	-2.90	-1.00	0.24	1.26	0.73	3.59*	-1.38	-3.65*	44.9	0.89	-8.58	-0.33
16 $N_1P_2K_0/k_1$	-5.77	-2.14*	0.66	3.75*	0.55	4.05*	-1.08	2.94*	49.3	1.06	-15.3	-0.58
17 $N_1P_2K_1/k_2$	-6.31	-2.15	0.87	0.43	0.42	1.62	-0.85	-1.81	77.3	1.52	-17.3	-0.78
18 $N_1P_2K_2/k_3$	1.13	0.33	0.30	1.31	-0.08	-2.55*	0.00	0.00	-27.3	-0.45	18.0	0.82
19 $N_2P_0K_0/k_1$	-8.55	-3.18*	0.87	4.94*	0.38	1.31	-0.46	-0.92	66.0	1.42	-39.8	-1.52
20 $N_2P_0K_1/k_2$	0.29	1.10	0.39	2.04*	-0.18	-0.74	-0.09	-0.22	25.3	0.50	-20.5	-0.69
21 $N_2P_0K_2/k_3$	-6.19	-3.22*	-0.08	-1.05	0.46	1.85	-0.89	-1.92	22.7	-0.11	-6.35	-0.99
22 $N_2P_1K_0/k_1$	-6.02	-2.16*	0.84	4.60*	0.64	4.43*	-1.18	-3.45	52.5	1.09	-49.5	-1.93
23 $N_2P_1K_1/k_2$	-6.43	-1.80	0.52	2.19*	0.29	1.06	-0.48	-0.98	62.5	1.01	-21.2	-0.66
24 $N_2P_1K_2/k_3$	-3.98	-1.29	0.32	1.58	0.31	1.45	-0.45	-1.15	63.0	1.19	-19.3	-0.59
25 $N_2P_2K_0/k_1$	-4.78	-2.06*	1.01	6.78*	0.23	0.92	-0.45	-1.03	61.5	1.54	-35.5	-1.35
26 $N_2P_2K_1/k_2$	-1.80	-0.67	0.27	1.49	-0.06	-3.48*	0.10	.38	3.66	0.78	-69.3	-2.24*
27 $N_2P_2K_2/k_3$	-4.63	-1.20	0.44	1.71	0.45	1.93	-0.73	-1.70	27.7	0.42	-39.8	-1.52

* Significant at 5% level.

quadratic time effect. Both linear and quadratic trends were significant only in five plots.

Copra yield on the other hand showed 12 plots with significant negative linear time trend and 12 plots with significant quadratic time trend. As in the nut yield both quadratic and linear trends were significant only in 5 plots.

The treatment combinations which show significant time trend were the same for both copra and nut yields (therefore the time series analysis in Chapter 4 is carried out using only nut yields).

As in the graphical analysis, the decrease in yield in the early stages of the experiment and increase in the latter stages were observed in almost all plots. This effect however is significant in many plots indicating that in the earlier stages the decline in yield was induced by age effect.

The increase in level of K in 1951 could perhaps be the cause for the significant increase in yield of the later stages of the experiment (see Chapter 4 for details). Whether this increase in the later stages is caused by (a) pure effect of additional K (i.e. nutrient effect) or (b) by giving rise to an increase in effect of the palm to respond to nutrients that was deteriorating in the early stages due to low K levels, cannot be concluded from these results.

The coefficients from lagged variables are significant in majority of plots for nuts (20 plots show significant ϕ_{11}, 17 for ϕ_{12}). This suggests that the <u>residual effects are significant</u> with regard to nut yields in majority of plots.

The number of plots showing significant lagged effects are much less for copra than for nut yield (11 for ϕ_{21} and 7 for ϕ_{22}) and this may mean that the residual nutrients do not influence the copra yield to the same extent as in the case of nuts.

Alternate years of manuring show no significant effect on the yield of either nut or copra yields (only one plot gave significant effect). A similar result to this was obtained by Eden _et al_, too. This perhaps could be because the effect of carry-over nutrients from manuring year to the blank year was high (see Chapter 4).

The coefficients of the dummy variables introduced to account
* for the change in K-level, in 1951 proved significant only in a few plots. However from the graphs showing the yield variation over the whole period, it is clear that in general those plots with no K or medium level of K up to that time exhibited a decline in yields and an increase from then on. The graph of the quadratic functions as well as the slope of the two linear trend lines for the two periods illustrates this clearly.

3.3 Analysis of the Overall Mean Response

The second stage of the analysis is to estimate the long term average effects of the nutreints N, P and K based on an analysis of the estimated $\alpha^{(1)}_{o,k}$ and $\alpha^{(2)}_{o,k}$. For these quantities represent the fertilizer effect alone and may be analysed by a weighted least squares procedure.

The mean overall responses are analysed for both copra and coconut and for two time periods. The first period consists of values from 1935-1950 and the second period consists of values from 1951-1965. The values for the second period are the overall means and the plot specific coefficients of the second dummy variable in equations 4.1a and 4.1b.

The fertilizer effect for 1935-1950 can be modelled as:

$$\hat{\alpha}^{(1)}_{o,k} = f(N,P,K) + \text{error} \tag{3.2a}$$

$$\hat{\alpha}^{(2)}_{o,k} = f(N,P,K) + \text{error} \tag{3.2b}$$

The fertilizer effect for the period 1951-1965 including the change of K can be modelled as:

$$\left\{\hat{\alpha}^{(1)}_{o,k} + \hat{\Delta}^{(1)}_{2,k}\right\} = f(N,P,K) + \text{error} \qquad (3.3a)$$

$$\left\{\hat{\alpha}^{(2)}_{o,k} + \hat{\Delta}^{(2)}_{2,k}\right\} = f(N,P,K) + \text{error} \qquad (3.3b)$$

The simple graphical analysis carried out in Chapter 3 suggests that the nutrient response in coconut follow a quadratic form. It was also seen that there is possible nutrient interactions as well. Therefore the functional form selected for the analysis of nutrient response in this study is a second order polynomial with the interaction terms in it.

The functional forms 3.2 and 3.3 given above therefore could be expressed more specifically as:

for nut yield in 1935-1950:-

$$\hat{\alpha}^{(1)}_{o,k} = \mu^{(1)} + \beta^{(1)}_{1}N_k + \beta^{(1)}_{2}P_k + \beta^{(1)}_{3}K_k + \beta^{(1)}_{11}N_k + \beta^{(1)}_{21}P_kN_k + \beta^{(1)}_{22}P^2_k + \beta^{(1)}_{31}N_kK_k + \beta^{(1)}_{33}K^2 + Z^{(1)}_k \qquad (3.4a)$$

for copra yield in 1935-1950:-

$$\hat{\alpha}^{(2)}_{o,k} = \mu^{(2)} + \beta^{(2)}_{1}N_k + \beta^{(2)}_{3}K_k + \beta^{(2)}_{11}N^2_k + \beta^{(2)}_{21}P_kN_k + \beta^{(2)}_{22}P^2_k + \beta^{(2)}_{31}N_kK_k + \beta^{(2)}_{33}K^2 + Z^{(2)}_k \qquad (3.4b)$$

for nut yield in 1951-1965:-

$$\left\{\hat{\alpha}^{(1)}_{o,k} + \hat{\Delta}^{(1)}_{2,k}\right\} = \mu^{(1)} + \beta^{(1)}_{1}N_k + \beta^{(1)}_{2}P_k + \beta^{(1)}_{3}K_k + \beta^{(1)}_{11}N^2_k + \beta^{(1)}_{21}P_kN_k + \beta_{22}P^2_k + \beta_{31}N_kK_k + \beta_{33}{}^2 + Z^{(1)}_k \qquad (3.4c)$$

for copra yield in 1951-1965:-

$$\left\{\hat{\alpha}^{(2)}_{o,k} + \hat{\Delta}_{1,k}\right\} = \mu^{(2)} + \beta^{(2)}_{1}N_k + \beta^{(2)}_{2}P_k + \beta^{(2)}_{3}K_k + \beta^{(2)}_{11}N^2_k + \beta^{(2)}_{21}P_kN_k + \beta^{(2)}_{22}P^2_k + \beta^{(2)}_{31}N_kK_k + \beta^{(2)}_{33}K^2 + Z^{(2)}_k \qquad (3.4d)$$

The $\mu^{(1)}$ and $\mu^{(2)}$ are constants for the equation 4.2 $\beta^{(3)}_j$ and $\beta^{(3)}_j$ are coefficients of the equation. $Z^{(1)}_k$ and $Z^{(2)}_k$ are error terms. The estimated coefficients and their t-statistic are given in the Table 4.3.

TABLE 3.2 THE CONSTANTS, $\hat{\beta}^{(1)}_{(j)}$, $\hat{\beta}^{(2)}_{(j)}$ VALUES AND THEIR COEFFICIENTS

	Nut Yield 1935-50		Nut yield 1951-65		Copra yield 1935-50		Copra yield 1951-65	
	$\hat{\beta}^{(1)}_j$	T-Value	$\hat{\beta}^{(1)}_j$	T-Value	$\hat{\beta}^{(1)}_j$	T-Value	$\hat{\beta}^{(1)}_j$	T-Value
N	29.229	+2.54*	10.594	+0.81	5.965	+0.87	-3.165	-0.39
P	-1.521	-0.13	-17.067	-1.31	-6.635	-0.97	-8.940	-1.10
K	23.778	+0.61	177.194	+3.98*	17.611	+0.75	+101.66	+3.68*
N^2	-2.840	-0.33	7.372	+0.76	-2.201	-0.43	+4.256	-0.71
NP	-4.948	-0.82	-0.222	-0.36	-1.365	-0.38	-0.255	-0.06
P^2	6.931	-0.92	8.024	+0.83	3.299	-0.65	+3.916	-0.65
NK	13.875	+1.15	10.398	+0.76	6.625	-0.92	+3.513	+0.41
PK	15.125	+1.26	14.517	+1.06	2.146	-0.30	+1.077	-0.13
K^2	-72.611	-2.14*	-82.456	-2.14*	-37.056	-1.83	-49.111	-2.05*
ant	1119.245		1027.41		506.921		479.479	

3.3.1 Results for nut yields

The nut yield showed a significant response in the first period. The N^2 term has a negative coefficient and though it is not significant, it could be seen as an indication that the response will decrease with increasing N. In the second period the response of the nut yield to N is not significant.

This non response (or very small response) of nut yield to N in the later period may be related to the build up of N in the soil, plant tissues etc to a considerable level.

The response of nut yield to P is not significant. The signs of the coefficients of the linear and quadratic terms of P show that P will lead to an increase in yield with the increase in quantity.

K shows a positive non-significant coefficient for the linear term and a negative significant coefficient for the quadratic term in the first period.

Considered together with the response indicated from the simple graphical analysis, it appears that there are grounds for stating that some positive response for K is present even though this decreases fairly rapidly with the increase in K. The response to K in the second period was high but showed a significant decrease with the increase of level.

Eden *et al*, in their analysis showed that the effect of K on nut number is highly significant at both levels. Though the results for N and P were similar in both Eden *et al* and this analysis, the results for K are different. This difference in the results could perhaps be attributed to the allowance for the temporal effects in the present analysis.

For both the periods, there were no significant interactions of nutrients for nut yield.

Significant interactions for a single dressing of N and K, and P and K for a double dressing were obtained by Eden *et al*.

3.3.2 Results for copra yield

The copra yield showed a small positive response for N in the first period and a small negative response in the second period. Based on the coefficient for linear and quadratic terms, both the periods show a decrease in response for additional quantities of N.

The response to P was similar for both periods but were very small.

K showed a very high significance in the second period and a very low significance in the first period. Both periods showed a significant decline in yield with increase of the quantity. This result does not tally with the results obtained by Eden *et al*. Their analysis show significant response to K throughout the first 15 years and a signficant positive response to addition of K.

In general the analysis shows that the nut yield responds significantly to N in the first period, though the increase of the number of nuts has not increased the copra out turn. P showed very little response in both nuts and copra, and as the positive value of the interaction term suggests, that P is required to obtain a good response from K. K showed significant effect on both nuts and copra in the second period.

3.3.3 The mean yield functions

The overall mean response (see Fig. 4.4) was maximised with respect to N, P and K for each period and for nut yield and copra yield to obtain optimum combination of N, P and K.

The nutrient combinations used in the factorial experiment which are nearest to the calculated optimum combination of nutrients were found based on the Eucledean distance (See Appendix D).

The nutrient combinations were then used to obtain the mean functions.

<u>Nut Yield</u>

Period I

$$Y^{(1)}{}_t = 1119 + 29.22N^* - 1.52P - 123.77K - 2.84N^2 - 4.9NP + 6.93P^2 + 13.87NK + 15.12PK - 6.99t + .74t^{2*} + .74Y^{(1)}{}_{(t-1)} - 0.84Y^{(2)}{}_{(t-1)} - 55.6X^{(1)} - 63X^{(1)}{}_2$$

Period II

$$Y^{(1)}{}_t = 1027.47 + 10.59N - 17.06P + 177.01K^* + 7.33N^2 - 0.22NP + 8.02P^2 + 10.39NK + 14.51PK - 82.45K^{2*} - 10.9t^2 + 1.05t^{2*} + 1.74Y^{(1)}{}_{(t-1)} - 3.50Y^{(2)}{}_{(t-1)} + 75X^{(1)}{}_1 - 49.9X^{(1)}{}_2$$

<u>Copra Yield</u>

Period I

$$Y^{(2)}{}_t = 506.92 + 5.96N - 6.63P + 17.61K - 2.20N^2 - 1.36NP + 3.2NP + 6.62NK + 2.14PK - 37.05K^2 - 4.78t^* - 1.01t^{2*} - 0.25Y^{(2)}{}_{(t-1)} - 0.06Y^{(1)}{}_{(t-1)} + 63X^{(2)}{}_1 - 69.3X^{(2)*}{}_2$$

Period II

$$Y^{(2)}{}_t = 479.478 - 3.16N - 8.94P + 101.66K^* + 4.25N^2 - 0.25NP + 3.69P^2 + 3.51NK + 1.07PK - 49.11K^2 - 6.31t^* + 0.56t^2 - 0.08Y^{(1)}{}_{(t-1)} - 0.85Y^{(2)}{}_{(t-1)} + 23.3X^{(2)}{}_1 + .63X^{(2)}{}_2$$

The mean functions for period 2 are more appropriate for the use in economic analysis than the functions for the first peirod, since most of the plots did not receive the required minimum of potassium in the first period (i.e. 1935÷50).

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* These coefficients were significant at 5% level.

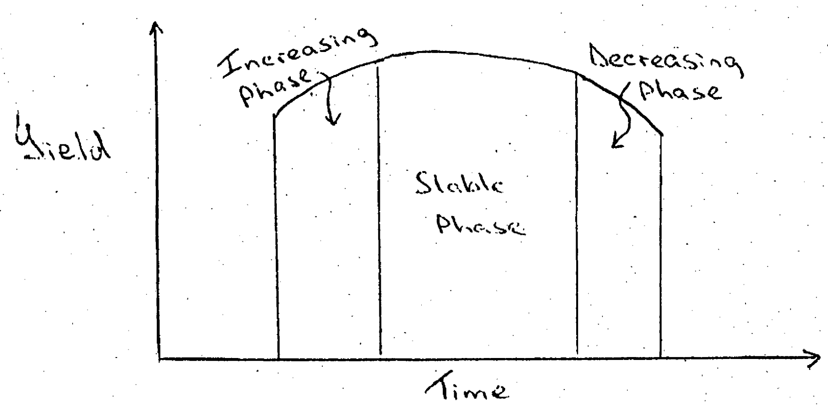
CHAPTER 4

TIME SERIES ANALYSIS

4.1 Introduction

It is generally accepted that the productive life of a crop consists of increasing, stable and decreasing phases (see Figure 4.1). It is suggested that in coconut palm, the first phase would be of 18-20 years of duration, the second phase 40-50 years and the yield will begin to decline with the onset of old age from then on (Menon and Pandalai, 1958).

Figure 4.1 PHASES OF PRODUCTION



Most of the economic decisions with regard to the production of coconut are based on this generally accepted yield patterns.

4.1.1 The phases of growth and level, composition and utilization of nutrients

The requirement of nutrients for growth and reproductive processes continue throughout the life time of the palm. However during different phases, the quantity of nutrients utilized for any of the above processes may vary. For instance in the first phase of production where the growth processes are higher than in the latter two phases, most of the absorbed nutrients are utilized for growth processes than for reproductive processes. Published work on the change in nutrient requirement of the palm during its productive life are lacking.

De Silva and Abeywardana (1970) showed that the growth of the important components of the coconut leaf increase up to an age of about 15 years and then tend to decrease with the age (see Figure 4.2a). Comparing bearing and non-bearing palms of ages 5 and 10 they showed that the magnitude of the growth components of the leaves of non-bearing palms was significantly greater as compared to that of bearing palms. These suggest that there is an inverse relationship between the vegetative and reproductive processes over the life cycle of the palm. Hence it could be expected that the pattern of utilization of nutrients by these two processes also would vary with age.

The growth of the stem of coconut palms reaches a peak value of 1.5m a year, during early stages of growth and falls to about 50 cms by about 25 years. This becomes progressively slow and at 40 years and over, the growth reduces to 10-15 cms a year (Child, 1974). This is illustrated in Figure 4.2b.

Quantitative data on the variation of the root growth are not available. However it could be expected that root growth also decreases with age.

From the above discussion it appears that after about 25 years the nutrient need for vegetative processes are gradually decreasing making more and more nutrients available for the reproductive purposes.

Since the growth of the stem drops sharply to a very low value at an age of about 40 years, it could be expected that the demand for nutrients by the vegetative processes are still reduced from then on.

The availability of nutrients for reproductive purposes thus may not be constant throughout the productive life. As the rate of growth of various components of the palm declines at different ages (examples of leaf and stem are given), the increase of the quantity available for reproduction would show considerable increase during the productive life of the palm.

Fig.4.2.a GROWTH CURVE FOR COCONUT LEAF

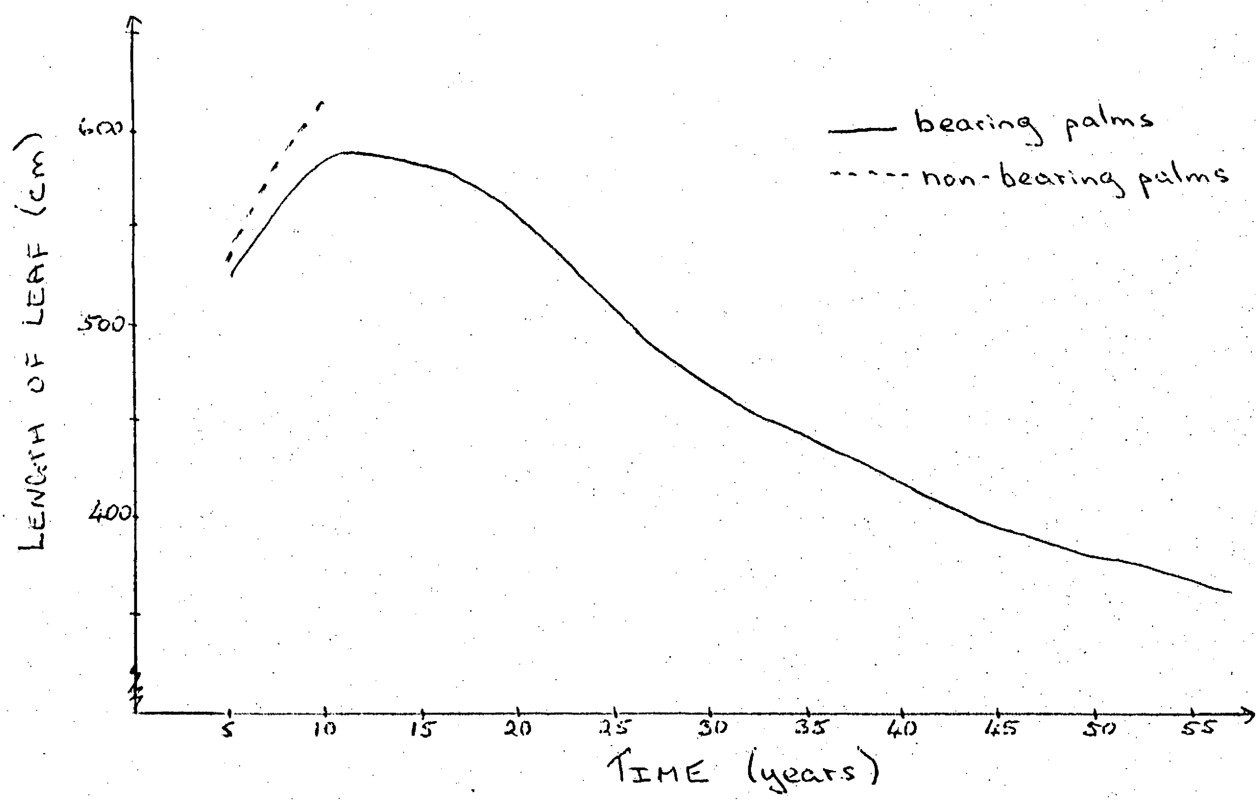
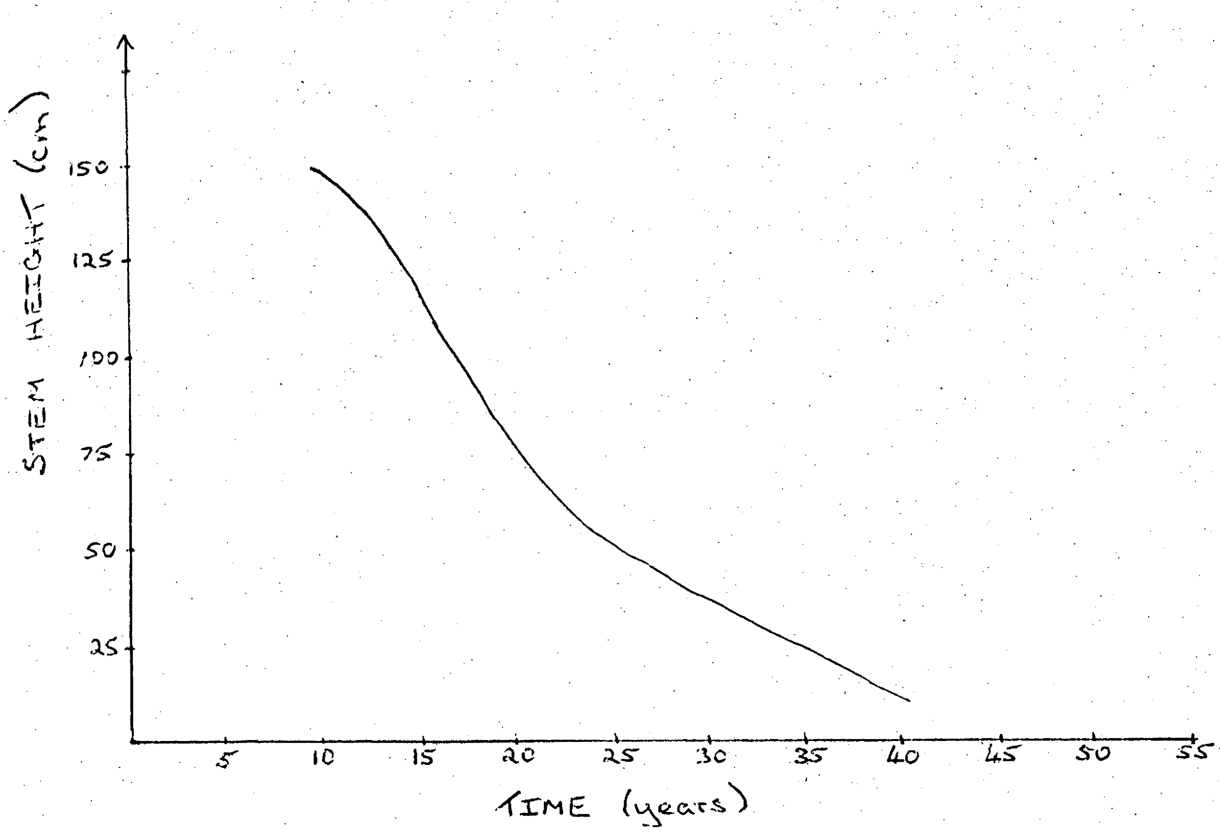


Fig.4.2.b GROWTH CURVE FOR COCONUT STEM



The nutrients released for reproductive purposes may also vary in composition. Thus marked differences in the level and composition of nutrients needed by the palm for optimum production may appear between different age groups.

Fertilizer policies should therefore be formulable bearing in mind the changes in growth of various components of the palm.

4.1.2 <u>Nutrient balance and the level and composition of nutrient</u>

As many nutrient elements often participate in the same biochemical transformation in the plant, the effect of one element is always closely associated with the presence of other nutrient elements. Therefore the yield and quality of a crop in any given period depend both on levels of individual nutrients and their relative amounts in plant tissues. In applying fertilizer to a crop, one has to therefore consider both the required level and the relative amounts of nutrients.

Fertilizer applications without considerable attention to these aspects may lead to decline in yields, more often associated with long term or permanent setbacks in the plant.

Correct proportion of nutrient elements in fertilizer mixture is also important from the point of view of the absorption of the plant. When incorrect proportions of nutrients are applied, a substantial portion of the nutrients tend to remain unabsorbed. Depending on the type of nutrient, soil and the climatic factors, these unutilized nutrients will subsequently be accumulated in the soil.

The level and proportion of nutrients in the fertilizer mixture therefore is of economic importance.

In coconut palm, the response to N and K may be restricted when one or the other is deficient (Smith, 1969). Smith showed that with increasing leaf N, the number of female flower production per inflorescence increased so that at low N levels lack of female flowers limits yield. Increase of K improves flower setting and the ability of the palm to carry fruit. He suggested that if N is adequate, the critical level of K needed in the leaf is 0.81%. When N is below 1.8%, the critical level of K is determined by the N/k ratio, which itself should not be less than a critical minimum. Assuming the N/k ratio remains constant when percent of N is below 1.8, the critical minimum would be 1.8/.8 = 2.25. At N levels below 1.8, the critical value of K can be calculated as N percent/2.25.

4.2 Method of Analysis

The yield of all plots which received the same nutreint treatment (two such plots in the experiment) were plotted against time. Similarly, the mean yields of all the plots which received low, medium and high levels of each of the nutrients N, P and K were plotted against time.

The time trends associated with each of these plots and groups of plots were estimated using quadratic functional forms. Two separate linear trends were fitted for the 1935-50 and 1951-65 periods since the fitted quadratic function suggested a clear change in the trends with the change in K level in 1950.

Only observed yields of nuts over the 30 year period were considered in this study.

4.3 Discussion of Results

The factorial experiment considered in this study was started when the palms were about 30 years old. Judging from the literature on yielding pattern of tall growing varieties of coconut grown under favourable management, soil and climatic conditions (see Menon and Pandalai, 1958; Child, 1974; Fremond, 1963), the palms in this experiment may be assumed to have been at its second phase of production (see Figure 4.1).

During the two periods, the experimental plots received two different levels of K while the levels of N and P remained the same in both periods. To investigate the effect on yield for the <u>same</u> treatment level, the yields of those plots receiving a particular nutrient treatment in the first period were used together with the yields of those plots which received same level after the change in K level in 1950.

A quadratic function was fitted to the observations. The shape of the fitted function for the mean of all plots which received K_1 and K_2 levels throughout are seen in Figure 4.4a.

These show U-shaped trend over the period.

Eden et al, noticed a tendency towards a general fall in yields in the last few years after 1951 and speculated that, it may be related to the ageing of the trees. However when the yields are examined for the longer period available for the present study, it is obvious that far from a general decline in yields, a considerable increase in yields has taken place. Since the experiment was discontinued in 1965, it is not possible to investigate whether this increase was sustained for a further period. In any case the observed pattern over time is quite striking and interesting.

The yield variation over the 30 year period exhibits more or less the same general pattern for majority of the nutrient treatments, (see Table 1, Appendix C).

The yield function for $N_0P_1K_0/k_1$* is given as an illustration in Figure 4.4. Figure 4.4a gives the quadratic function and Figure 4.4b gives the linear trends for the two periods (1935-50 and 1951-65).

The yield pattern shown by majority of plots exhibit a decline in yield in the first period (1935-50) and an increase in the second period (1951-65).

Plots which received the nutrient combinations $N_0P_1K_2/k_3$ and $N_1P_2K_1/k_2$ showed an increase throughout the 30 year period (see Figure 3.5) and plots which received $N_0P_0K_2/k_3$ and $N_1P_1K_1/k_2$ showed a decrease

* This indicates a low level of nitrogen, medium level of phosporus and a low level of potassium (stepped up by a medium level of potassium). Similar notation will be used throughout the discussion.

Fig.4.3 YIELD TRENDS FOR SAME LEVELS OF K

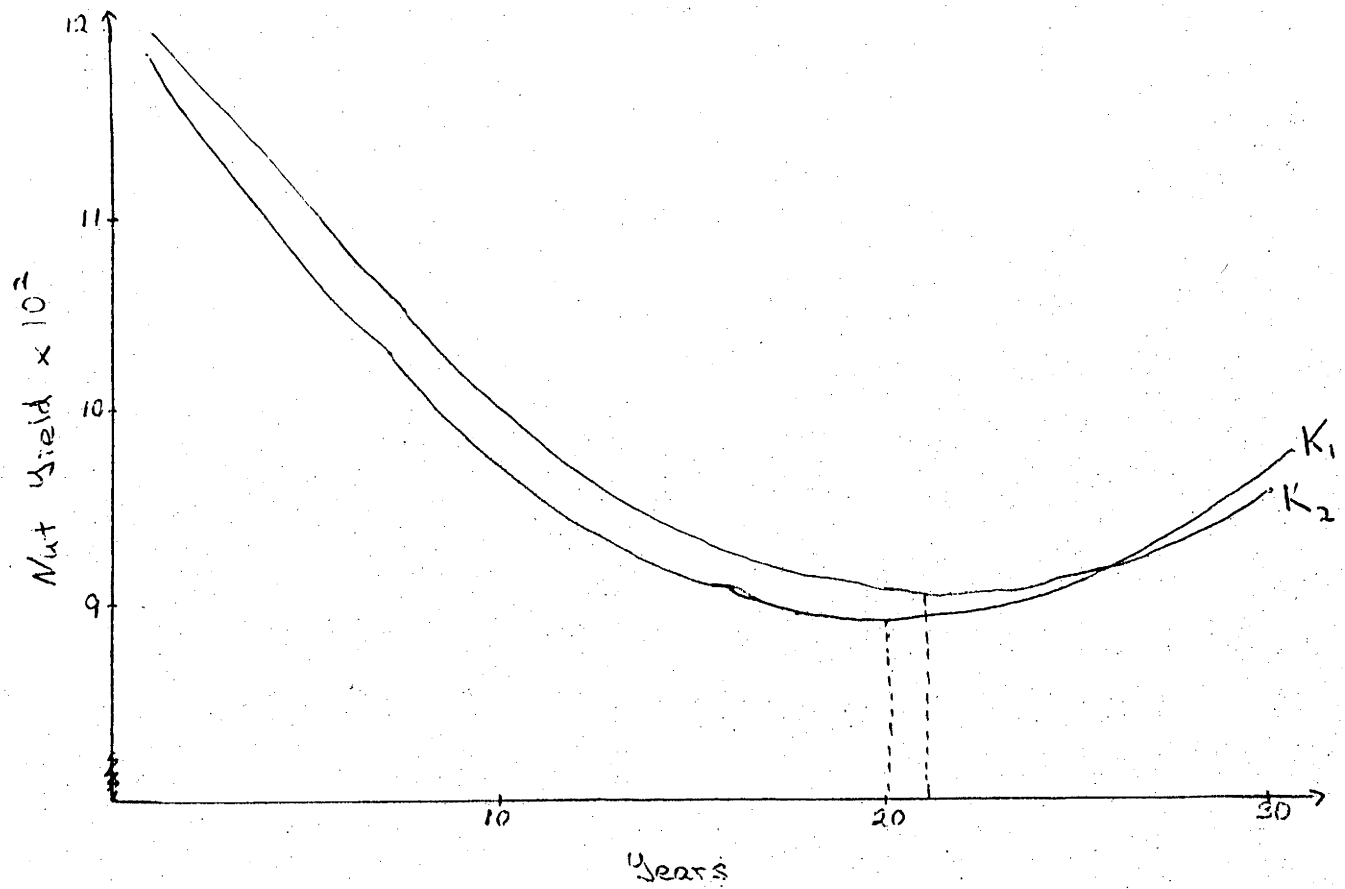


Fig.3.4 QUADRATIC AND LINEAR YIELD TRENDS FOR THE 30 YEAR PERIOD

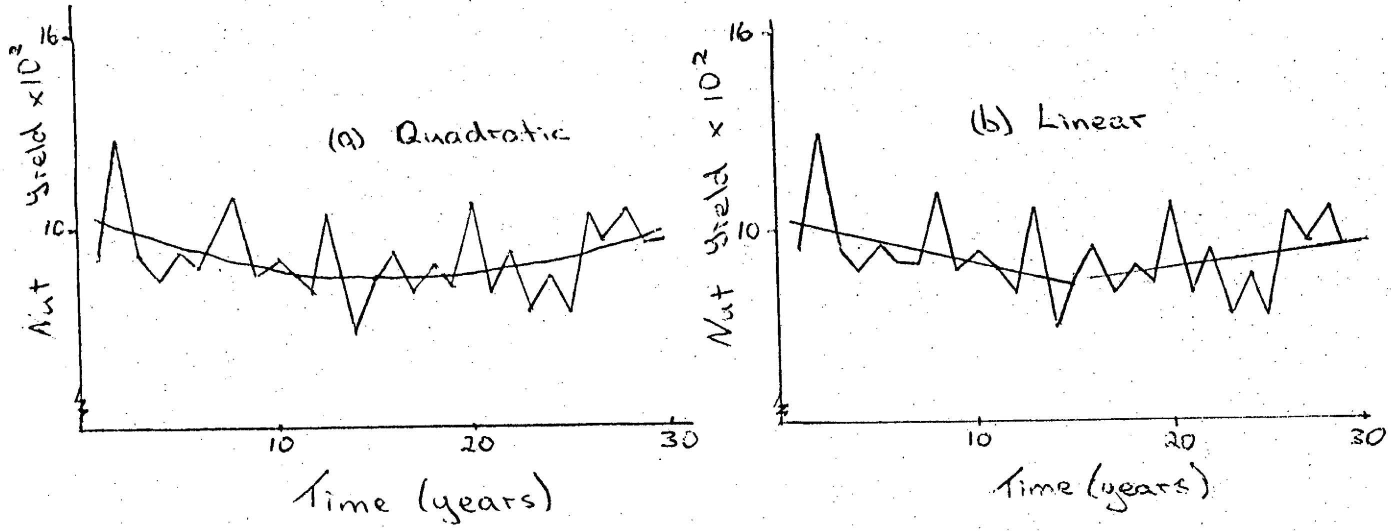


Fig.4.5.a INCREASING YIELD TREND SHOWN BY $N_oP_1k_{2/k_3}$

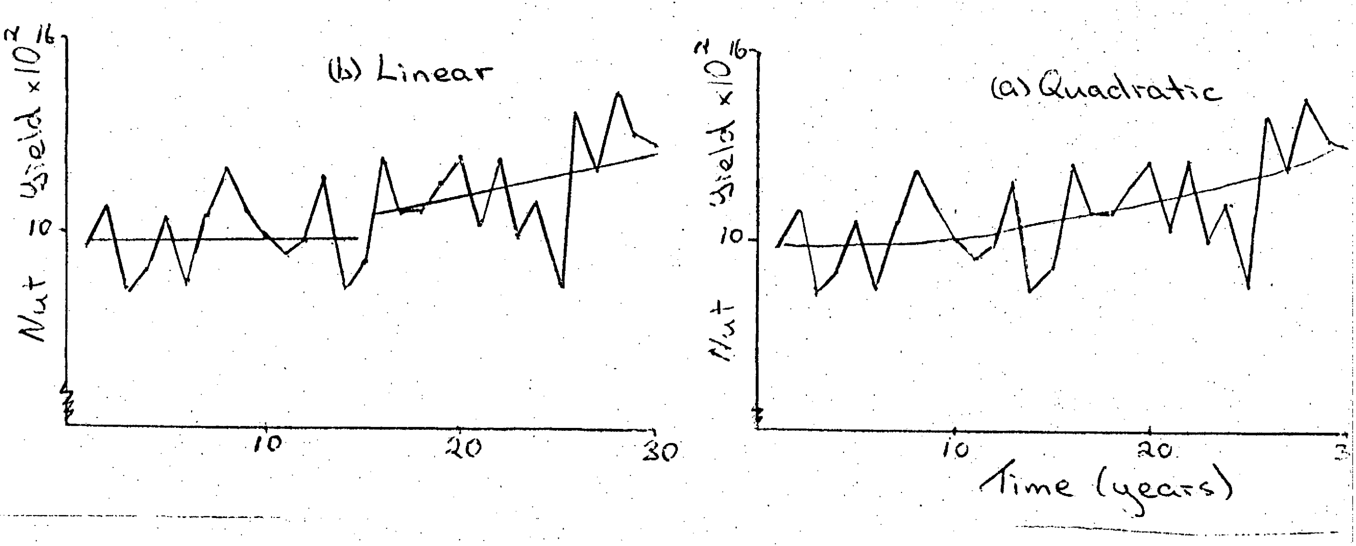


Fig. 4.5.b INCREASING YIELD TREND SHOWN BY $N_1P_2k_{1/k_2}$

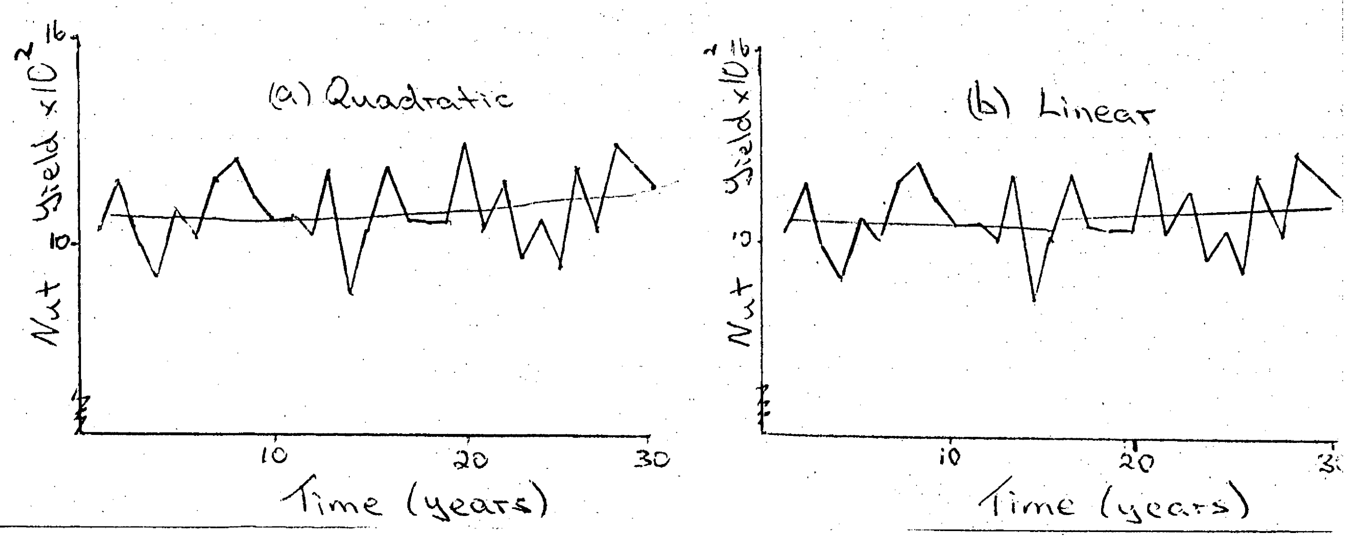
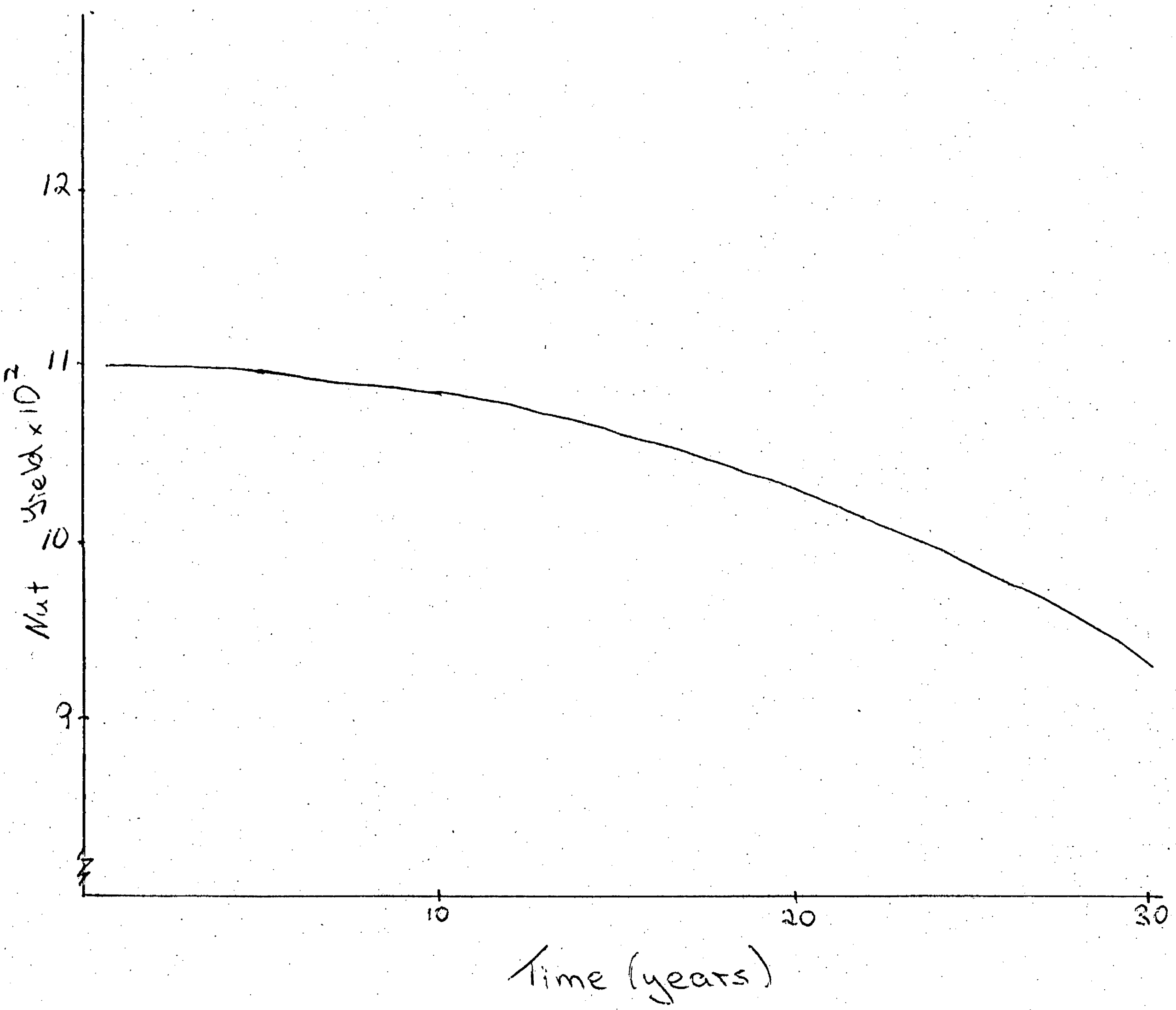


Fig.4.6 STABLE AND DECLINING YIELD TREND



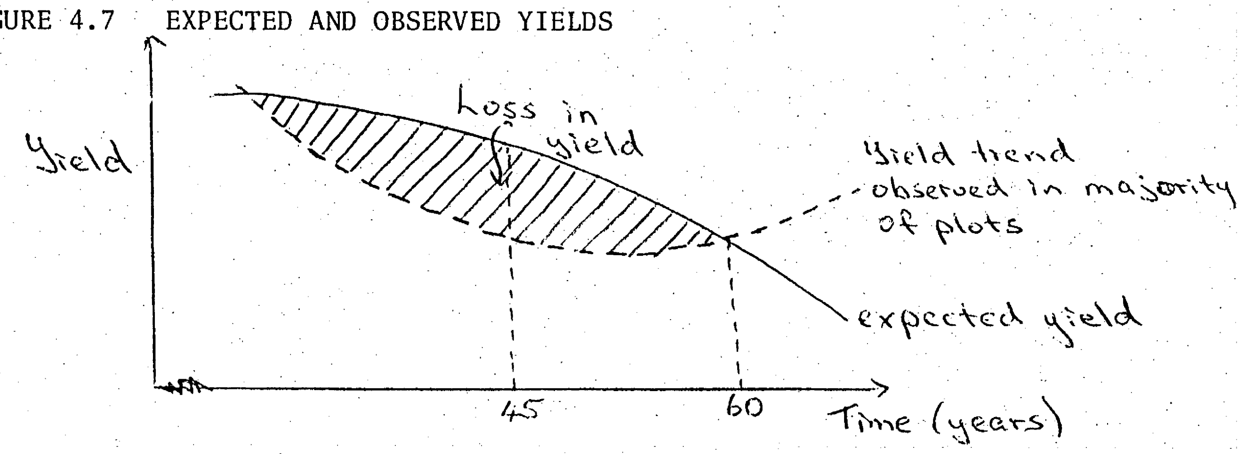
in yield throughout the period (see Figure 4.8). The $N_2P_0K_2/k_3$ plot showed more or less a stable yield pattern in the first period and a decline in the second period (see Figure 4.6).

According to Menon and Pandalai if a pure age effect was in operation during this period, we would have expected a stable yield since palms during this phase were in the 30-60 age group.

However from the decline observed in majority of plots when compared with the small number of plots which showed increase in yield (in the 1st period) and also with that of the general pattern as suggested by Menon and Pandalai and others, it appears that what majority of plots show is not the yield pattern that could be expected when a palm operates at a maximum capacity.

This decline in yield at early stages of the palm (under majority of nutrient combinations) while it has the potential to yield at a higher level (expected yield) is a great economic loss (see Figure 4.7) and is an aspect that needs investigation. Such an investigation is important because most of the important decisions on fertilizer application and replanting depend on yielding pattern of the palm.

FIGURE 4.7 EXPECTED AND OBSERVED YIELDS



These plots which had a U-shaped yield curve over the experimental period had the minimum points of the fitted quadratic function at different years. These points ranged from the 12th to the 24th year (see Table 4.4).

This aspect is further disucssed in section 4.3.4.

TABLE 4.1 THE POINT OF CHANGE IN YIELD TREND

	Treatment	Lowest Point
1	$N_0P_0K_0/k_1$	16.0
2	$N_0P_0K_1/k_2$	15.6
3	$N_0P_0K_2/k_3$	-
4	$N_0P_1K_0/k_1$	16.0
5	$N_0P_1K_1/k_2$	14.0
6	$N_0P_1K_2/k_3$	-
7	$N_0P_2K_0/k_1$	14.8
8	$N_0P_2K_1/k_2$	18.0
9	$N_0P_2K_2/k_3$	11.2
10	$N_1P_0K_0/k_1$	18.0
11	$N_1P_0K_1/k_2$	18.8
12	$N_1P_0K_2/k_3$	16.0
13	$N_1P_1K_0/k_1$	15.2
14	$N_1P_1K_1/k_2$	24.4
15	$N_1P_1K_2/k_3$	12.0
16	$N_1P_2K_0/k_1$	16.0
17	$N_1P_2K_1/k_2$	-
18	$N_1P_2K_2/k_2$	15.2
19	$N_2P_0K_0/k_1$	20.0
20	$N_2P_0K_1/k_2$	18.0
21	$N_2P_0K_2/k_2$	-
22	$N_2P_1K_0/k_1$	16.8
23	$N_2P_1K_1/k_2$	16.0
24	$N_2P_1K_2/k_3$	18.4
25	$N_2P_2K_0/k_1$	16.4
26	$N_2P_2K_1/k_2$	15.2
27	$N_2P_2K_2/k_3$	13.6

1. A lowest point was not shown by these treatments during the 30 year period.

4.3.1 Response to different levels of K

The rate of yield increase and decrease in the period under the original manurial scheme and the period under the augmented K respectively were very high in K_o plots as compared to K_1 and K_2 plots (see Figure 4.8). However the difference in decrease of the response in the first period, and the increase of the response in the second period for the plots which received K_1 and K_2 in the first period were quite small (see Table 4.5). This indicates that the yield increase due to the increase of K follow a non linear trend, with the response decreasing with increasing K.

TABLE 4.2 RESPONSE TO DIFFERENT LEVELS OF K

	Quadratic[1]			Linear 1st period		Linear 2nd period	
	$\hat{a}_1$	$\hat{a}_{11}$	$\hat{\beta}$	$\hat{a}_1$	$\hat{\beta}$	$\hat{a}_1$	$\hat{\beta}$
K_0/k_1	1.21	-40.27	1152.70	-23.94	1117.19	14.49	779.69
K_1/k_2	.49	-16.56	1149.44	- 9.97	1132.77	3.66	1004.94
K_2/k_3	.44	-13.46	1153.90	- 7.58	1139.13	4.68	1048.96

This great aspect could be further examined by looking at the plots which had no nutrients other than K (see Table 3.5).

TABLE 4.3 THE YIELD TRENDS FOR K_0, K_1 AND K_2 PLOTS

	Quadratic			Linear 1st period		Linear 2nd period	
	$\hat{a}_1$	$\hat{a}_{11}$	$\hat{\beta}$	$\hat{a}_1$	$\hat{\beta}$	$\hat{a}_1$	$\hat{\beta}$
$N_0P_0K_0/k_1$	.89	-23.83	1029.57	-20.92	1026.00	7.31	806.75
$N_0P_0K_1/k_2$	.39	-11.81	1127.96	-10.12	1135.19	1.48	1067.99
$N_0P_0K_2/k_3$	.33	-21.72	1160.81	-19.44	1160.46	-11.12	940.28

The non-linear response to increase of K is markedly shown in the yield trends for the K_o, K_1 and K_2 plots that are presented in Table 4.2. While increase of the K level to K_1 from K_o has decreased the rate of decline in yield in the first period, a further increase has increased the rate of decline. This indicates that the response to K could possibly be modelled with a quadratic function.

A further aspect that is clear from the observations in the plot which received the higher level of K (K_2) is the decreasing yield trend when no other nutrients are applied (see Figure 4.9).

Fig.4.8 YIELD TRENDS IN K PLOTS WITH CHANGE IN K LEVEL IN 1950

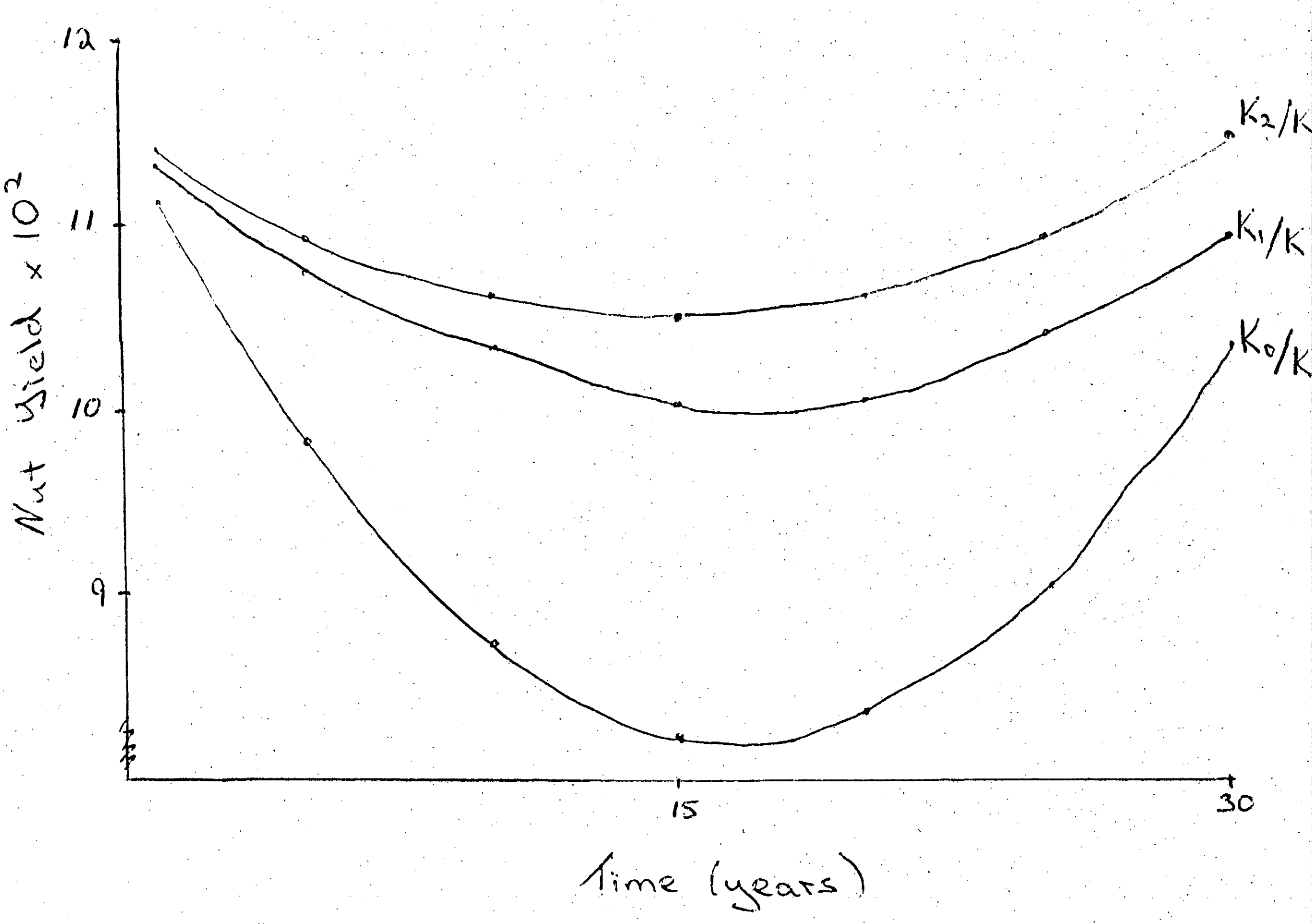
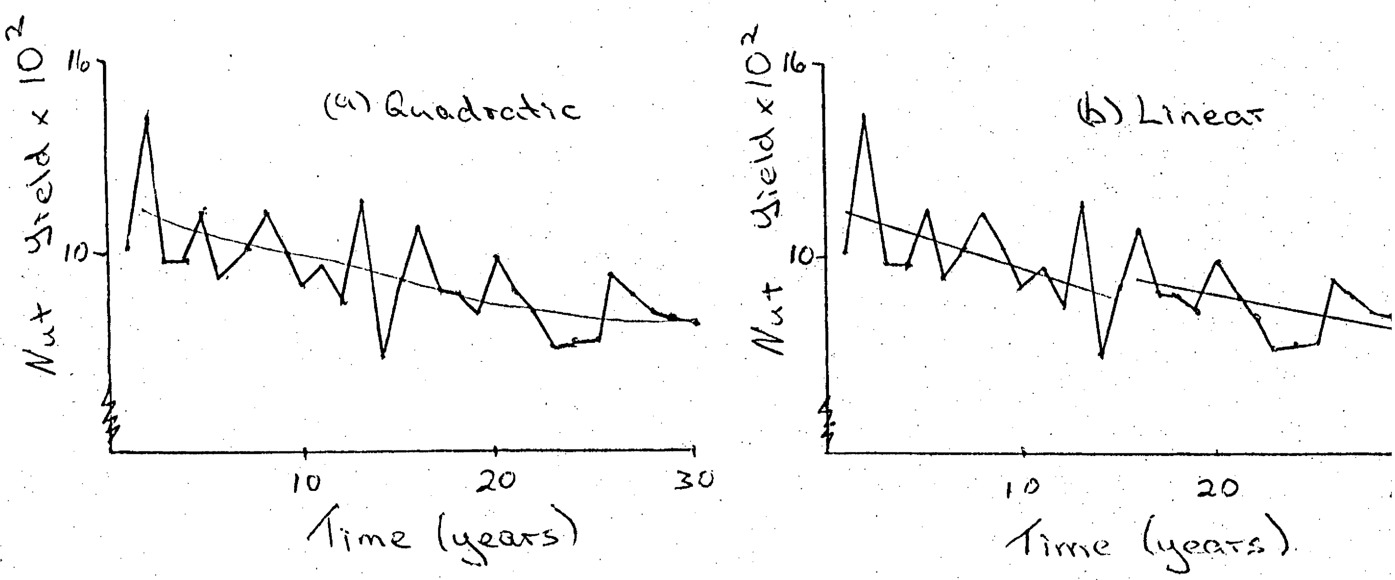


FIGURE 4.9 YIELD TRENDS IN $N_oP_oK_2/k_3$ PLOT



This observation helps to provide information on the interaction of K with other nutrients. For this purpose trends shown by $N_0P_1K_2$, $N_0P_2K_2$, $N_1P_0K_2$ and $N_2P_0K_2$ were examined.

TABLE 4.4 INTERACTIONS BETWEEN NK AND PK

	Quadratic			Linear 1st period		Linear 2nd period	
	$\hat{a}_1$	$\hat{a}_{11}$	$\hat{\beta}$	$\hat{a}$	$\hat{\beta}$	$\hat{a}$	$\hat{\beta}$
$N_0P_0K_2$	.33	-21.72	1160.81	-19.44	1160.46	-11.12	940.29
$N_0P_1K_2$	.40	- 1.61	970.06	+ 1.12	970.93	+12.66	1062.40
$N_1P_0K_2$	.47	-11.42	1075.98	- 3.29	1049.79	+ 9.56	995.87
$N_2P_0K_1$	.28	- 8.49	1194.85	- 5.18	1187.74	+ 2.53	1137.94
N P K	.20	.48	1101.73	- 2.30	1108.72	- 8.12	1068.68

The trends shown in the Table 4.4 suggest that the interactions between P_1K_2, P_2K_2, N_1K_2 lead to a positive response while interactions of K_2 with higher levels of N lead to reduction in yield. The interaction of P_1 and K_2 appear to be very much favourable than any of the above interactions.

Furthermore the interaction between very high level of K and N also appear to lead to a negative response. Therefore in the specification of functional forms for nutrient response functions it will be <u>important to introduce interaction terms</u> to take into account interactions between nutrients and the interactions between nutrients and the trends.

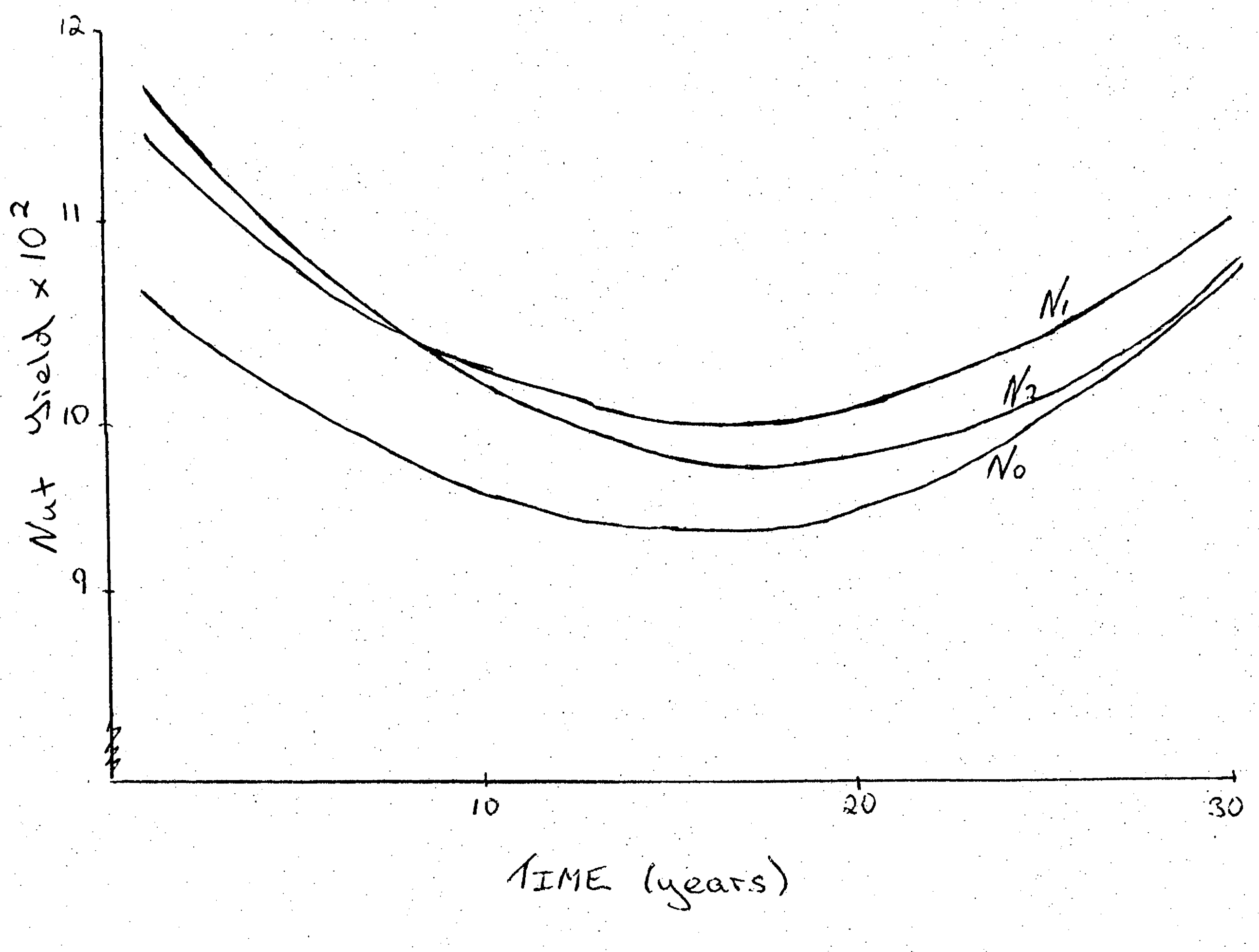
4.3.2 <u>Response to different levels of N.</u>

As in the plots receiving different levels of K, there appears to be a decrease in yields with the application of higher levels of N. The rate of increase over time observed in the second period for higher N levels is much smaller than the rate of increase observed for N_o and N_1 levels. (See Figure 4.10). Thus it may be necessary to include N in nutrient response functions in both linear and quadratic forms as for K.

TABLE 4.5 RESPONSE TO DIFFERENT LEVELS OF N

	Quadratic			Linear 1st period		Linear 2nd period	
	$\hat{a}_1$	$\hat{a}_{11}$	$\hat{\beta}$	$\hat{a}$	$\hat{\beta}$	$\hat{a}$	$\hat{\beta}$
o	.64	-19.54	1084.29	-11.85	1068.99	+7.05	934.23
1	.64	-21.08	1167.74	-11.92	1144.70	+7.33	974.61
2	.73	-25.76	1197.28	-15.44	1173.44	+6.09	962.90

Fig.4.10 RESPONSE TO N



4.3.3 Response to different levels of P

The rate of decline in yield appears to be slightly greater when there is no P as compared to P_1 and P_2 levels. There is however no appreciable difference in the rate of decline in yield or the rate of increase in yield for the P_1 and P_2 plots. The rate of increase however is very small in the second period for P_o plots.

Though the K level was increased in the second period the P_o plot failed to show sufficient increase in yield as compared to P_1 and P_3 (see Figure 3.1). This gives sufficient indication that P is an important element in the nutrition of the coconut palm and that increase of K gives increase of yield in conjunction with P.

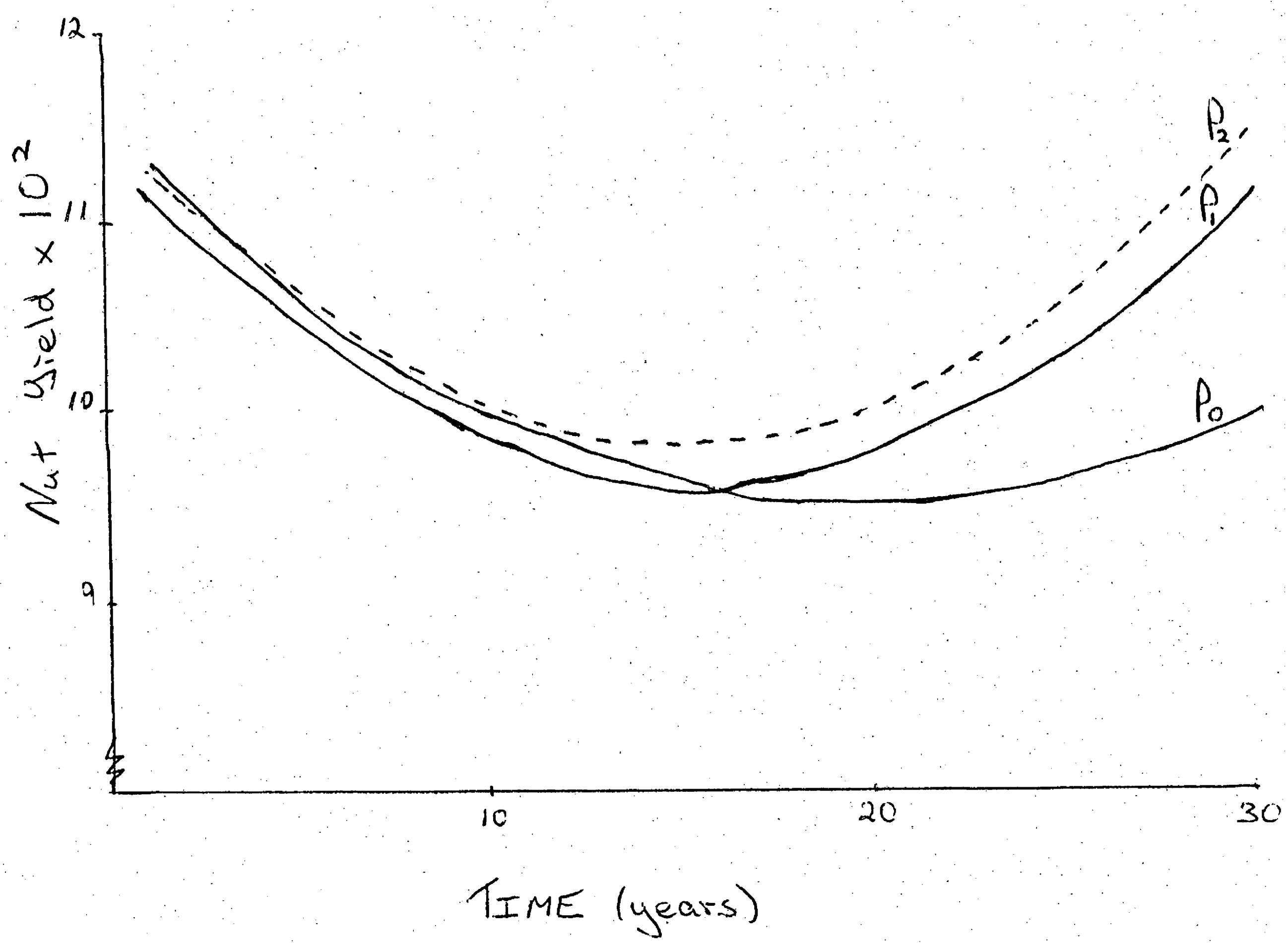
TABLE 4.6 RESPONSE TO DIFFERENT LEVELS OF P

	Quadratic			Linear 1st period		Linear 2nd period	
	$\hat{a}_1$	$\hat{a}_{11}$	$\hat{\beta}$	$\hat{a}$	$\hat{\beta}$	$\hat{a}$	$\hat{\beta}$
P_o	.23	-20.82	1156.69	-14.52	1144.41	1.22	961.17
P_1	.74	-22.85	1137.73	-12.97	1114.85	9.17	946.00
P_2	.75	-22.70	1154.89	-12.05	1127.86	10.07	964.57

It is known that the soil was substantially rich in P at the beginning of the experiment from the heavy application of organic P in the pre-experimental period, hence these results could indicate that in the first period some P was available from the soil even for the plots which received no P application. However this would have been exhausted in that period and the lack of P in the next period prevented the trees from responding to the increase in K level after 1950 to the same extent as other plots which continually received P. To sum up therefore the observations indicate:

i) importance of a certain minimum level of P,

Fig.4.11 RESPONSE TO P



ii) the decrease in rate of response over time to increased levels of P.

iii) substantial positive interaction between P and K.

4.3.4 The yield pattern: a discussion and possible explanations

An important aspect relevant to fertilization policies emerges from the graphical analysis.

The U-shaped yield pattern observed in plots receiving same nutrient treatment in both periods is one which is normally not expected in perennial crops, particularly in coconut in this age group. This shape is particularly interesting in that it would have very important implications for the whole strategy of improving the coconut industry: the 'economic' life time of the coconut palm has to be reviewed in the light of these observations and the problem of rehabilitation of old trees by fertilization instead of replanting has to be more carefully studies.

As was indicated earlier in the discussion, while the change in K-level in 1950 did influence the yield pattern, it alone cannot account for the change.

To explain this phenomenon, the hypothesis is put forward that a combination of two factors operating during this period would have produced the U-shaped yield pattern:

The two factors are:

i) nutrient imbalance

ii) the changing proportion of the nutrients utilized for growth and reproductive processes in the palm.

4.3.4.1 Nutrient imbalance

The yield decline shown by plots receiving K_2 in the first period (apart from K_o and K_1 plots) suggests that even the highest level of K originally applied did not provide a sufficiently balanced nutrient combination, for the palm to yield at its maximum capacity.

Based on Smith's findings, it could be expected that the nutrient imbalance would have been caused by one of the following or by both.

i) Critical level of K (0.80%) was not reached and there was sufficient N available in the palm (1.8% or above).

ii) That N was below the critical level (1.8%) and the critical minimum ratio of N/k = 2.25 was not reached.

Since both the above conditions give rise to a deficiency in either K or N, the palm may not yield at its optimum capacity. Subsequently due to the accumulation of unutilized nutrients (caused by imbalance) in soil and plant tissues, it may cause further imbalance giving rise to decreasing yields over the years.

The leaf analysis data available for this experiment (only data for the 30th year are available; see Chapter 1) shows that even at the highest K level (K_3) used in the experiment during the 30 years of K level in the 30th year in the leaf was 0.66 and was below the critical level. The N in the leaf reached 1.91.

The above experimental evidence suggest that there would have been a deficiency even in the first period of the experiment. Apart from this it could be expected that in K_oK_1 and K_2 plots either one or both the above conditions would have existed giving rise to a decline in yields of varying degree.

Figure 4.8 illustrates a case of N deficiency. Here K at medium level with only the naturally available N has given rise to decrease in yield throughout the 30 year period. The increase of K in the second period in this plot, would have further reduced the N/k ratio.

It could be expected that the N/k ratio in K_1, K_1 and K_2 plots would have decreased at varying degrees. Thus any increase in K would increase the N/k ratio enabling more utilization of N (if N is adequately available) and hence increasing the yield. Therefore it could be expected that in all the plots where there were increases in yield in the second period it was at least in part due to the decrease of the N/k ratio.

When K level is low, the N that is absorbed may not be fully utilized. Furthermore since K helps in the root development enabling the palm to take up more nutrients, the nutrient uptake will be reduced adding to the effects caused by imbalance. Increase of K therefore while restoring the balance will also enable the palm to tap nutrients from a larger volume of soil thus enhancing the yield.

4.3.4.2 Age specific need of nutrients

The change in proportion of nutrients needed by the palm for different biological processes was mentioned earlier.

If the growth processes of the palm were higher in the first period than in the second period, then the nutrient levels that were provided in the first period may not have been sufficient and hence it showed a decline in yield. At early stages of the productive life of a crop such higher growth activities could be expected.

In the second period if the nutrient requirements for the growth processes of the palm were less than in the first period, then a lower quantity of nutrients would have been sufficient and a higher proportion of them would have been utilized for reproductive purposes and hence the yield would have increased.

Therefore it is possible to expect a U-shaped yield curve even under a balanced manurial regime and this points the need for more empirical research into estimation of yield functions over time for perennial crops. Such information would also then be useful for formulating optimal age specific fertilizer dosages.

4.4 Alternate Years of Manuring

The application of manure in this experiment was carried out biennially. Since the yield observations for all the plots exhibited similar annual fluctuations, a X^2 test was carried out to determine whether yields in a given year were associated with the application of fertilizer or not, in that year.

The method adopted in testing* is illustrated below by taking the plots which recieved $N_0P_1K_2/k_3$ and $N_2P_0K_1/k_2$ treatments as examples.

The annual yields for the above two plots are given in Figures 4.12a and 4.12b.

FIGURE 4.12a. YIELDS UNDER TREATMENT $N_0P_1K_2/k_3$

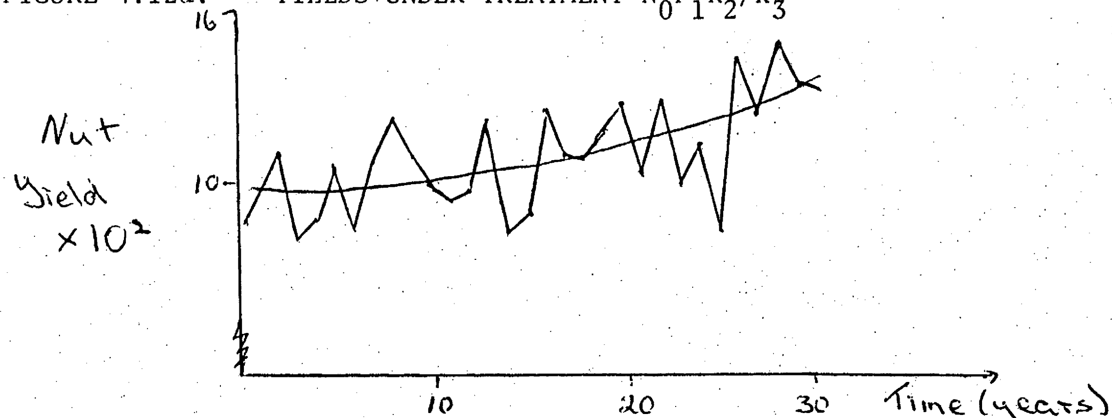
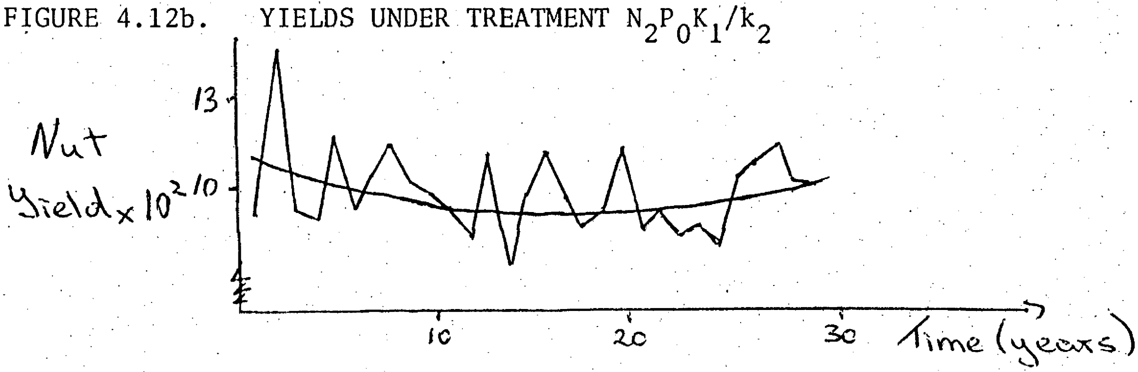


FIGURE 4.12b. YIELDS UNDER TREATMENT $N_2P_0K_1/k_2$



Tables 4.10a and 4.10b show whether the yields in the year of manuring and blank year are higher or lower than the yield of the previous year; higher yield is devoted by a + sign and lower yields by a - sign.

TABLE 4.7a THE YIELD VARIATION FOR TREATMENT $N_0P_1K_2/k_3$

Manuring:	+		+		-		+		-		+		-		+		+		+		+		+		+		+		-
Blank:		-		+		+		-		-		+		+		-		+		-		-		-		-		-	

TABLE 4.7b. THE YIELD VARIATION FOR TREATMENT $N_2P_0K_1/k_2$

Manuring:	+		-		-		+		-		-		+		+		-		+		+		+		+		+		-
Blank:		-		+		+		-		-		-		+		-		+		+		-		-		-		-	

* See Kendall, M. G. (1948) The Advanced Theory of Statistics, Vol.1, Charles Griffin and Co., Ltd., London, pp.209-307.

The frequency of positive and negative yields for the year of manuring and the blank year and their theoretical frequencies if there was no relationship between the application of manure and yield in that year are tabulated below:

	Negative	Positive	Theoretical Frequency
Manuring:	4	11	7.5
Blank:	9	5	7.0

TABLE 4.8a. THE OBSERVED AND EXPECTED FREQUENCIES OF HIGH AND LOW YIELDS FOR THE TREATMENT $N_0P_1K_2/k_3$

	Negative	Postive	Theoretical Frequency
Manuring:	5	10	7.5
Blank:	9	5	7.0

TABLE 4.8b. THE OBSERVED AND EXPECTED FREQUENCIES OF HIGH AND LOW YIELDS FOR THE TREATMENT $N_2P_0K_1/k_2$

The value of X^2 for the treatment $N_0P_1K_2/k_3$ is:

$$= \frac{(4-75)^2 + (11-7.5)^2}{7.5} + \frac{(9-7)^2 + (5-7)^2}{7}$$

$$= 4.41$$

The tabular value for X^2 at 5% level of significance is 3.84 and hence it could be expected that there is a significant association between the year of manuring and yield.

The value of X^2 for the treatment $N_2P_0K_2/k_3$ is:

$$= \frac{(5-7.5)^2 + (10-7.5)^2}{7.5} + \frac{(9-7)^2 + (5-7)^2}{7}$$

$$= 2.81$$

This is less than 3.84.

In this case there appears to be no association between the application or non application of manure and the yield in that year.

Similarly X^2 values were calculated for all plots which received different treatments. The results are presented in Table 4.9. Then the X^2 values of all the plots were added and tested to see whether any significant association existed between manuring/non manuring and the yields obtained in those years.

When looked at individually only six plots ($N_0P_1K_0/k_1$, $N_0P_1K_2/k_3$, $N_0P_2K_2/k_3$, $N_1P_0K_0/k_1$, $N_2P_0K_0/k_1$ and $N_2P_2K_0/k_1$) appeared to show such a significant relationship. However the overall X^2 value is 65:39 with 27 degrees of freedom, while the probability of obtaining a X^2-value > 40.11 is less than 5% with 27 degrees of freedom. Therefore this shows a significant relationship when considered individually, the overall results for all the 27 treatments shows a very significant association between manuring/non manuring and the yields in those years.

These results are important since Eden et al analysis concluded that while their results suggested that yields in manured years appeared to be higher than in the blank years, they were not significant statistically. With the information available for a longer period and using the method outlined above, it can now be concluded that there is strong evidence to state that in general yields in manured years tend to be higher.

The implication of this finding appears to be that further investigation should be carried out to determine whether it would be commercially justified to apply fertilizer annually instead of biennially. This would depend on the cost of application and the increase in yield that could be expected from such practices.

TABLE 4.9 X^2 VALUES, PROBABILITIES AND THE DEGREES OF FREEDOM FOR EACH TREATMENT

	Treatment	X^2	P	ν
1	$N_0P_0K_0/k_1$	2.80	0.094	1
2	$N_0P_0K_1/k_2$	1.66	0.201	1
3	$N_0P_0K_2/k_3$	0.35	0.554	1
4	$N_0P_1K_0/k_1$	6.24*	0.011	1
5	$N_0P_1K_1/k_2$	0.88	0.348	1
6	$N_0P_1K_2/k_3$	4.41*	0.034	1
7	$N_0P_2K_0/k_1$	2.81	0.093	1
8	$N_0P_2K_1/k_2$	1.74	0.191	1
9	$N_0P_2K_2/k_3$	5.84*	0.016	1
10	$N_1P_0K_0/k_1$	9.97	0.001	1
11	$N_1P_0K_1/k_2$	1.74	0.191	1
12	$N_1P_0K_2/k_3$	0.60	0.437	1
13	$N_1P_1K_0/k_1$	2.81	0.093	1
14	$N_1P_1K_1/k_2$	1.74	0.191	1
15	$N_1P_1K_2/k_3$	0.66	0.416	1
16	$N_1P_2K_0/k_1$	1.78	0.192	1
17	$N_1P_2K_1/k_2$	0.35	0.554	1
18	$N_1P_2K_2/k_3$	0.35	0.554	1
19	$N_2P_0K_0/k_1$	4.24*	0.040	1
20	$N_2P_0K_1/k_2$	2.04	0.157	1
21	$N_2P_0K_2/k_3$	1.21	0.138	1
22	$N_2P_1K_0/k_1$	1.95	0.168	1
23	$N_2P_1K_1/k_2$	1.31	0.294	1
24	$N_2P_1K_2/k_3$	0.06	0.806	1
25	$N_2P_2K_0/k_1$	5.17*	0.023	1
26	$N_2P_2K_1/k_2$	1.21	0.273	1
27	$N_2P_2K_2/k_3$	1.66	0.205	1
		65.39		27

*$X^2>3.84$ are significant at 5% level.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The present analysis attempts to incorporate explicitly the temporal effects in analysing the nutrient response data for coconut as far as possible, within the limitation of the data.

The results have yielded some useful additional information on the response of coconut to nutrients N, P and K which have some important economic implications for the coconut industry of Sri Lanka.

The results could be summarised as follows:

5.1 Response to Nitrogen

The response of the number of nuts to nitrogen was positive and was significant. Higher levels of nitrogen used in the experiment showed a tendency to depress the yields.

Though the nut yield responded very well to nitrogen fertilizer, the yield of copra showed very little response, indicating that the increase in the number of nuts has not effected the copra out-turn.

Continuous application of nitrogen fertilizer appears to give rise to a build up of this nutrient either in the soil or in the plant tissues. This perhaps could be the reason for the lack of response to N in the subsequent years of the experiment. Whether the build up is in the soil or in the plant tissue has to be determined by analysis of soil and plant tissues. If the build up is in plant tissues it will be a plant factor which is of economic importance in the fertilizer application for coconuts.

Cook (1958) commenting on the observations made on the nitrogen response in this factorial experiment suggested that, the continuous application of nitrogen may have caused accumulation of this nutrient in the soil and hence gave rise to a lack of response for further applications.

5.2 Response to Phosphorus

Though nuts and copra yields showed very little response to phosphorus, there was some evidence to suggest that the nutrient element is important in the nutrition of the coconut palm and hence the yield.

The lack of sufficient response observed for this element in the factorial experiment can be attributed to the sufficient to availability of organic phosphorus that was already in the soil However there is evidence to suggest that the palm tended to improve its response to phosphorus while the organic phosphorus content of the soil gradually depleted.

Unlike nitrogen, the phosphorus was seen to effect both nut and copra yields to the same extent.

5.3 Response to Potassium

Both nut and copra yields show a very high response to potassium. The graphical analysis showed that the plots which did not receive as much as 2lbs of potassium fertilizer per palm showed marked decline in yield.

The nut and copra yields show a tendency to decrease yields at higher levels of the nutrient. Also it is seen that the potassium nutrition is important in both copra and nut yields.

5.4 Interactions

The graphical analysis showed that the presence of phosphorus was necessary for potassium to show yield response in coconut. A similar interaction was seen with regard to nitrogen and potassium also. However the statistical analysis shows that these nutrient interactions are not significant though they are positive.

The statistical analysis shows that the interaction between nitrogen and phorsphorus is negative and is not significant. However the graphical analysis shows a very clear negative interaction effect between the two elements.

5.5 Carry-over of Nutrients

Carry-over of nutrients was significant under certain nutrient treatments. However due to data constraint, the exact estimation of the carry-over nutrients in each period or the amount of carry-over in the soil and the plant tissues was not possible.

5.6 Effect of Alternate Years of Manuring

The results of the analysis shows that the alternate years of manuring did not effect the copra or the nut yield, in all the plots other than one.

5.7 General Effect of Fertilizer Application

The ability of the palm to respond to nutrients even at fairly late stages of the productive life was clearly seen. The experiment considered in this study was conducted during the 30-60 year age range of the palms and the analysis shows that the fertilizer tended to increase the yields at much later age of the palm. This shows that proper fertilizer application could arrest the tendency towards decline of yields with age. Since the experiment used in the present analysis was discontinued in 1965 (i.e. when the palms were 60 years old), any further information on the ability of fertilizer to reduce age induced decline in yield at higher ages cannot be obtained.

In this regard it may be valuable to continue the four factorial experiments conducted by the Coconut Research Institute of Sri Lanka even after the trees pass the age of 60 years.

5.8 Economic Implications

Some of the additional information that were derived from the analysis give clear indication of the direction that should be followed to increase the coconut production in Sri Lanka.

The coconut production in Sri Lanka can be increased by rehabilitation of the existing plantation or by replanting. As to which method is to be followed depends on many factors and needs proper cost benefit analysis with the due recognition of agronomic factors, (see Etherington, 1974 for a similar discussion on Tea in Indonesia).

Nathanael (1968) estimated that about 7,000 acres of coconut lands need to be replanted every year, based on the assumption that plantations over 60 years of age exhibit decreasing yields (see Chapter 1 also). However what is clear from the present analysis is that even at 60 years of age the palms receiving a majority of fertilizer treatments have not begun to show any signs of yield decline (see Figures 3.1, 3.3, 3.4 and 3.5). Hence rather than replanting at the age of 60 years as suggested by Nathanael (1968), a major portion of the 7,000 acres of coconut land which reach the age of 60 years can be brought into increased production each year by proper fertilizer treatment and the replanting could be delayed.

In general most of the coconut plantations in Sri Lanka can be made to increase their yields by the application of fertilizer.

Whether such fertilization is the best economic policy as compared to replanting needs to be evaluated. This leads to the problem of finding an optimal replanting age and an optimum fertilizer regime (see Section 5.11).

A basic necessity for such an economic evaluation is the proper specification of the nutrients response function and in the present analysis it was seen that the data constraint poses problems in the specification (see Section 5.10).

At this point it is important to look at the actual progress of coconut production under the fertilizer subsidy scheme. The figures given in Table 1.1 for the progress in increase of the quantity of fertilizer used per acre and the corresponding increase in the yield per acre appears to contradict the results obtained in the fertilizer experiment.

This phenomenon needs careful investigation and some of the factors that may have contributed to this are:

a) while coconut production did not show substantial improvement, the fertilizer application may have arrested a decline that may have set in, in the absence of fertilization.

b) while no exact figures are available on the age structure of the plantations, it is suspected that a fair percentage could be very old. Though from the experiment we are unable to judge the response to fertilizer at ages over 60 or so, it seems reasonable to think that at such higher ages, trees may not respond so well to fertilizer and this may have affected the overall production.

c) fertilizer allowed for coconut under subsidy scheme is used for other crops: There is evidence that the coconut fertilizer is widely used for rice and some other crops. But no quantitative estimates of these are available.

d) management practices that are neccesary to provide the higher response to fertilizer may be lacking in most holdings, especially in view of the fact that most holdings are owned by small holders (70% of the holdings owned by small holders - See Chapter 1).

e) statistical errors in estimation of coconut production: It is estimated that only 50% of the total production comes from large estates and the rest comes from small holdings whose production figures are only estimated.

5.9 Implications for Future Research

More research is needed to investigate fully the economics of fertilizer application. Need for these additional research arises partly because of the temporal effects associated with the nutrient response of the crop.

5.9.1 Carry-over effects

The use of a carry-over function to estimate carry-over nutrients in soil (see Stauber and Burt 1973) may not be appropriate in coconut.

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APPENDIX A

A.1 Use of Coconut products.

Leaf: Unopened flower is tapped to obtain sap. Using the say following are obtained.

i) toddy (untreated sap) used for drinking, has a very low percentage of alcohol.

ii) arrack, obtained by distilling toddy.

iii) jaggary (a form of sugar), obtained by evaporation of sap.

iv) vinegar, obtained by acetic fermentation of sap.

Nut: i) milk ('coconut water') of young nuts is used as a refreshing drink.

ii) meat, used to make curry and generally cooking.

iii) Copra, (dried meat of the coconut) used to obtain coconut oil.

iv) poonac (the residual cake left after the oil is pressed out of the copra). This serves as an animal feed.

v) desiccated coconut, (dried and finely shredded coconut) used mainly in confectionery industry.

vi) coir (coconut fibre derived from the husk) used in mats, brooms, rope, etc.

vii) oil, used in the manufacture of food products such as margarine, cooking oil etc and in the manufacture of soap, candles, etc.

viii) shell, charcoal.

APPENDIX A

A.2 The Climatically Suitable Cultivation Area.

Agroclimatic factors which are very essential for the growth of coconut are taken in defining the climatically suitable cultiavtion area for coconut.

Rainfall: The optimum annual amount of rainfall needed is 1,500 to 2,000 m.m. and is fulfilled in the lowlands immediately bordering the highlands. The annual rainfall minimum needed is 1,000 m.m., and this is reached in NW and SE coastal plains. Both these areas suffer from unfavourable growth conditions due to a dry period of at least 3 months with a minimum of 50 m.m. of rain. This is disadvantageous for coconut.

Temperature: The coconut palm requires an optimum annual average of 27-28°C and is found in the entire lowlands of Sri Lanka up to an altitude of 100 to 150m.

Relative Humidity: An optimum annual relative humidity of 80-90 percent is needed and is found in the entire island.

Sunshine Duration: 2,000 hours per year is required and is attained throughout the lowlands.

On the above basis two large areas in the island are climatically suitable for the cultivation of coconut.

a) The lowlands in the west and southwest, extending from approximately Puttatam to Tangalla to a varying depth between coast and highlands.

b) A wide lowland belt in the east of the island, extending roughly fron Mullative to Panawa.

APPENDIX B

TABLE 1 NUTS (THOUSANDS PER ACRE) - MAIN EFFECTS

	Year	Manuring	Mean yield	N'	N''	P'	P''	K'	K''
	1936	M	3.67	+0.22	-0.07	-0.12	+0.08	+0.06	-0.08
	1937	..	4.78	+0.31	+0.46*	-0.10	+0.10	+0.31	+0.02
	1938	M	3.60	+0.32*	+0.01	+0.09	0.00	+0.19	+0.10
	1939	..	3.53	+0.20*	-0.07	-0.06	-0.08	+0.14*	+0.17
	1940	M	4.24	+0.38*	+0.11	-0.08	+0.13	+0.50*	+0.05
	1941	..	3.55	+0.33*	-0.02	+0.02	-0.05	+0.28*	+0.09
	1942	M	3.96	+0.44*	-0.02	0.00	+0.20	+0.66*	+0.21
Period A	1943	..	4.28	+0.32	-0.09	-0.06	+1010	+0.51*	+0.16
	1944	M	3.80	+0.28*	-0.05	-0.15	+0.08	+0.72*	+0.30*
	1945	..	3.60	+0.22*	-0.02	-0.01	+0.06	+0.56*	+0.10
	1946	M	3.60	+0.24*	-0.04	-0.02	+0.13	+0.70*	+0.27*
	1947	..	3.40	+0.18	-0.21	-0.05	+0.10	+0.70*	+0.19
	1948	M	4.09	+0.24*	+0.13	+0.06	+0.05	+0.86*	+0.26*
	1949	..	2.73	+0.16	-0.23	+0.02	-0.05	+0.76*	+0.21
	1950	M	3.52	+0.20	+0.07	-0.14	+0.20	+1.10*	+0.22
	1951	..	4.02	+0.12	-0.00	-0.07	+0.18	+1.24*	+0.29*
	1952	M	3.51	+0.24	-0.03	+0.04	+0.10	+1.09*	+0.40*
	1953	..	2.87	0.00	-0.03	+0.16	0.00	+0.54*	+0.11
Period B1	1954	M	3.53	+0.14	-0.04	+0.12	+0.09	+0.94*	+0.32*
	1955	..	4.19	+0.22	-0.04	+0.32	+0.07	+0.50*	+0.13
	1956	M	3.40	+0.06	-0.02	+0.09	+0.08	+0.54*	+0.18
	1957	..	3.68	+0.10	-0.16	+0.16	+0.05	+0.52*	+0.20
	1958	M	3.10	+0.10	-0.11	+0.11	+0.06	+0.65*	+0.20
Period B2	1959	..	3.46	+0.10	-0.10	+0.24	-0.01	+0.55*	+0.16
	1960	M	2.98	+0.04	-0.17	+0.20	+0.13	+0.54*	-0.12

Mean Yield 3.64
Series A uniform manuring
B1 augmented potassium computer analysis.
B2 augmented potassium, supplementary years.
* Significant P = 0.05
Pooled Standard Error for General Responses ± 0.014=2.86 percent,
Pooled Standard Error for Additional Responses ±0.121=3.31 percent.

APPENDIX B

TABLE 2 NUT RESPONSES (MEAN OF 22 YEARS) (THOUSANDS PER ACRE)

General Responses

	N'	P'	K'	S.E.
Mean	+0.23**	+0.02	+0.61**	±0.0727
Linear	-0.0112*	+0.0120*	+0.0286**	±0.00505
Quadratic	-0.0008	+0.0008	-0.0046**	±0.000713

Additional Responses

	N''	P''	K''	S.E.
Mean	-0.02	+0.08	+0.18*	±0.0839
Linear	-0.0073	+0.0013	+0.0098	±0.00584
Quadratic	+0.0007	-0.0005	-0.0015	±0.000823

* and ** = Significant at P = 0.05 and 0.01 respectively

APPENDIX B

TABLE 3 COPRA (IN UNITS OF 10 LB. PER ACRE) - MAIN EFFECTS

	Year	Manuring	Mean Yield	N'	N''	P'	P''	K'	K''
	1935	..	153	-1	-2	-1	-6	+6	-3
	1936	M	177	+9	-4	-6	+6	+5	-3
	1937	..	230	+14	+10	-4	0	+11	+2
	1938	M	172	+10	-4	+2	+1	+12	+5
	1939	..	142	+4	-9	-2	-4	+10	+8
	1940	M	193	+11	0	-6	+5	+28	+3
	1941	..	155	+9	-6	0	-2	+20	+5
	1942	M	180	+12	-7	-4	+9	+41	+12
	1943	..	194	+6	-9	-6	+3	+36	+11
Period A	1944	M	174	+4	-9	-9	+2	+46	+18
	1945	..	164	+4	-4	-3	+2	+38	+9
	1946	M	144	+2	-9	-3	+2	+38	+14*
	1947	..	163	+3	-12	-4	+2	+46*	+13
	1948	M	172	+2	-2	0	+1	+52*	+13*
	1949	..	121	+3	-12	0	-5	+48*	+15*
	1950	M	162	+8	-2	+2	+8	+62*	+17*
	1951	..	190	-3	-8	-8	+5	+75*	+18*
	1952	M	164	+4	-7	-1	+4	+66*	+25*
	1953	..	152	-8	-7	+4	-3	+38*	+12*
Period B1	1954	M	174	0	-5	+4	+2	+61*	+20*
	1955	..	210	+4	-9	+9	+2	+38*	+11
	1956	M	165	-4	-7	0	+1	+36*	+10
	1957	..	162	-2	-12	+1	-2	+34*	+8
	1958	M	136	-2	-8	+1	0	+40*	+11*
Period B2	1959	..	140	-2	-8	+4	-4	+30*	+9
	1960	M	138	-2	-10	+7	+3	+34*	+8

Mean Yield 166.
Period A uniform manuring
B1 augmented potassium computer analysis
B2 augmented potassiu, supplementary years.
* Significant P = 0.05.
Pooled Standard Error for General Responses ±5.4=3.25 per cent.
Pooled Standard Error for Additional Response ±6.2=3.73 per cent.

APPENDIX B

TABLE 4 COPRA RESPONSES (MEAN OF 23 YEARS) IN UNITS OF 10 LB. PER ACRE)

General Responses:

	N'	P'	K'	S.E.
Mean	+4	-2	+36**	±4.22
Linear	-0.33	+0.28	+2.08**	±0.266
Quadratic	-0.02	+0.04	-0.24**	±0.311

Additional Responses:

	N"	P"	K"	S.E.
Mean	-5	+1	+11*	±4.87
Linear	-0.32	+0.01	+0.72*	±0.307
Quadratic	+0.03	-0.03	-0.10*	±0.0359

* and ** = Significant at P = 0.05 and 0.01 respectively.

APPENDIX

TABLE 2 INTERACTIONS (FIRST ORDER). NUTS (THOUSAND PER ACRE)

Between general responses

	N'P'	N'K'	P'K'	S.E. ±
Mean	-0.030	+0.186*	+0.084	0.0771
Linear	-0.00630	+0.00710	+0.00511	0.00536
Quadratic	+0.00061	-0.00108	-0.00045	0.000756

Between general and additional responses

	N'P"	N'K"	P'K"	S.E. ±
Mean	-0.055	+0.112	+0.088	0.0890
Linear	+0.01370*	+0.00220	+0.00842	0.00619
Quadratic	-0.00038*	-0.00100	-0.00020	0.000873

	N"P'	N"K'	P"K'	S.E. ±
Mean	-0.015	+0.032	+0.072	0.0890
Linear	+0.00500	+0.01140	-0.00072	0.00619
Quadratic	+0.00008	-0.00140	-0.0125	0.000873

Between additional responses

	N"P"	N"K"	P"K"	S.E. ±
Mean	-0.160	+0.245*	+0.225*	0.1028
Linear	-0.01080	-0.00300	-0.01365	0.00715
Quadratic	+0.00075	-0.00090	-0.00050	0.001008

* Significant, P = 0.05

APPENDIX C

TABLE 1 VALUES OF THE COEFFICIENTS AND CONSTANTS FOR THE TWO PERIODS

PERIOD I			PERIOD II		
Treatment	$\hat{a}$	$\hat{\beta}$	Treatment	$\hat{a}$	$\hat{\beta}$
$N_0P_0K_0$	-20.92	1026.00	$N_0P_0K_1$	7.31	806.75
$N_0P_0K_1$	-10.12	1135.19	$N_0P_0K_2$	1.48	1067.99
$N_0P_0K_2$	-19.44	1160.46	$N_0P_0K_3$	-11.12	940.29
$N_0P_1K_0$	-14.19	1030.85	$N_0P_1K_1$	7.91	828.80
$N_0P_1K_1$	-8.18	1007.28	$N_0P_1K_2$	8.02	908.74
$N_0P_1K_2$	1.22	970.93	$N_0P_1K_3$	12.55	1062.40
$N_0P_2K_0$	-21.81	1150.84	$N_0P_2K_1$	24.12	836.57
$N_0P_2K_1$	-9.94	1089.52	$N_0P_2K_2$	3.49	960.64
$N_0P_2K_2$	-3.29	1049.79	$N_0P_2K_3$	9.56	995.87
$N_1P_0K_0$	-16.79	1012.74	$N_1P_0K_1$	6.01	755.26
$N_1P_0K_1$	-10.02	1206.89	$N_1P_0K_2$	2.48	1052.80
$N_1P_0K_2$	-5.18	1187.74	$N_1P_2K_3$	2.53	1137.94
$N_1P_1K_0$	-27.65	1148.31	$N_1P_1K_1$	27.93	709.40
$N_1P_1K_1$	-16.28	1282.36	$N_1P_1K_2$	-2.90	1051.75
$N_1P_1K_2$	-6.57	1063.46	$N_1P_1K_3$	6.48	1008.19
$N_1P_2K_0$	-19.23	1142.17	$N_1P_2K_1$	12.13	894.60
$N_1P_2K_1$	-2.35	1085.05	$N_1P_2K_1$	3.13	1083.28
$N_1P_2K_2$	-3.20	1173.55	$N_2P_0K_3$	8.15	1078.25
$N_2P_0K_0$	-32.31	1360.07	$N_2P_0K_2$	7.27	898.26
$N_2P_0K_1$	-13.55	1101.90	$N_2P_0K_2$	3.17	922.54
$N_2P_0K_2$	-2.30	1108.72	$N_2P_1K_3$	-8.12	1068.68
$N_2P_1K_0$	-29.09	1146.49	$N_2P_1K_1$	17.41	735.82
$N_2P_1K_1$	-10.29	1198.00	$N_2P_1K_2$	6.38	1067.90
$N_2P_1K_2$	-5.69	1185.99	$N_2P_2K_3$	-1.37	1140.99
$N_2P_2K_0$	-33.45	1037.85	$N_2P_2K_1$	20.27	551.70
$N_2P_2K_1$	-8.99	1088.78	$N_2P_2K_2$	7.69	973.84
$N_2P_2K_2$	-6.21	1333.79	$N_2P_2K_3$	2.06	1306.40

APPENDIX D

Nutrient Combination Nearest to Calculated Optimum

Let the calculated optimum combination of N, P and K be M_N, M_P and M_K and the coded form of the nutrient treatment used in the experiment be L_N, L_P, L_K.

Then the distance between the calculated optimum and the nutrient treatment used in the experiment is:

$$D = L_N - M_N)^2 + (L_P - M_P)^2 + (L_K - M_K)^2$$

The values of D are compared and the nutrient treatment which gives the smallest D is selected as the nutrient combination which is nearest to the calculated optimum.